

TARDEC

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THERMOPLASTIC COMBAT
IDENTIFICATION PANEL (CIP) INSERT

JANUARY 1997

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Armaments Command
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By _____

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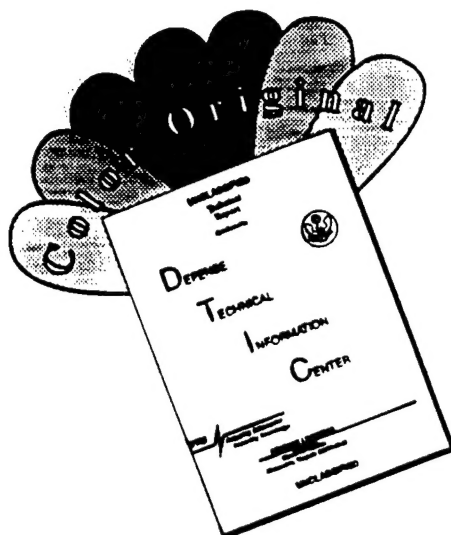
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PREFACE

This report documents the work performed from February 1995 to December 1996 in the Lightweight Structures Team. Questions regarding this investigation should be referred to the U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC), ATTN: Lightweight Structures Team (AMSTA-TR-D), Building 215, Warren, Michigan, 48397-5000, Telephone: AUTOVON/DSN 786-6065, Commercial (810) 574-6065, FAX (810) 574-8667.

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THERMOPLASTIC COMBAT IDENTIFICATION PANEL (CIP) INSERTS

1. INTRODUCTION

1.1 NEED / REQUIREMENT OBJECTIVE STATEMENT

CIP kits were produced and fielded as a quick fix solution for anti-fratricide. They were deployed to Bosnia and fielded to other contingency forces, but are in short supply thereby necessitating a larger production capability at a lower cost. The integral portion of a kit is a panel insert which is currently made of formed aluminum and covered with tan and green color I.D. tape.

The objective of this project is to reduce the cost per kit by reducing the panel cost. The panel costs can be significantly reduced by changing the material from aluminum to thermoformed plastic. The plastic panel will reduce the material and forming costs, eliminates the CARC painting process, improves the durability of the panel, and reduces the logistic burden by providing a common panel for all insert sizes. The common plastic panel can easily be sheared into the required sizes without producing sharp edges.

There are 72 aluminum panels with their own NSNs at an average aluminum panel cost of \$65 (The range is \$ 40 -\$165). Commercial procurement of thermoplastic composite material in corrugated configuration is \$ 25 per panel.

HQDA has forecasted OMA requirement for 28,000 panel inserts for each of FY 1998 and FY 1999.

1.2 OBJECTIVES OF THIS INVESTIGATION

The purpose of this investigation was to evaluate corrugated thermoplastic panel inserts for use as combat identification panel (CIP) inserts. These thermoplastic CIP inserts replace only the existing formed corrugated aluminum panels, but use the existing combat identification tan and green colored I.D. tapes. The existing tapes coefficient of thermal expansion (CTE) closely matches the CTE of aluminum. The current aluminum CIP panels were painted with CARC paint. The tape adhesive was designed to be consistent with the paint system and should be removable if it need to be removed and/ or repaired in the field.

The effects of panel size, shape, bending stiffness and CTE mismatch were studied on the Boltaron thermoplastic corrugated panel insert's performance as well as flat Boltaron panels. The laboratory study conducted here simulates the field temperatures only and not the humidity and moisture. Solar heating laboratory tests were conducted for a week to study solar loading effects on the performance of the I.D. tape on thermoplastic panels.

The field tests on the corrugated panel inserts are in progress and will be reported separately.

2. THERMOPLASTIC SHEET MARKET STUDY

A telemarketing study was conducted to identify the manufacturers and suppliers of thermoplastic sheets in U.S. industries. This study was narrowed to thermoplastic sheets of 0.125 inch thick as this was determined to be the most optimum thickness for CIP inserts. As a result of this market study, a large number of manufacturers and suppliers of different thermoplastic sheets were identified. The market study included information on material properties such as coefficient of thermal expansion (CTE) and elastic modulus and other information such as sizes of commercially available sheets. The details of this market study are presented in Table 1.

3. STUDIES ON 24 INCHES LONG AND 12 INCHES WIDE THERMOPLASTIC FLAT PANELS

Some preliminary tests were conducted using the available thermoplastic flat panels. The test matrix for 24 inches long and 12 inches wide specimens is presented in Table 2. The thermoplastics investigated were: Azdel, ABS-21, Boltaron 4330. The green and tan colored combat I.D. tapes were applied to all specimen types.

Boltaron is the registered trade name of Empire Plastics Inc. for polyvinyl chloride (PVC) or Acrylic/PVC thermoplastics. Azdel is the registered trade name of Azdel Inc. for fiber glass reinforced polypropylene thermoplastic.

The thermal cycle applied on these thermoplastic sheets during laboratory tests is presented in Table 3

Azdel panels produced no tape wrinkles after 5 hours of exposure to 160° F. Boltaron 4330 produced small amounts of tape wrinkles. ABS-21 panels produced large amounts of wrinkles. Besides, ABS-21 panels were badly warped. These results were expected, because of CTE mismatch between tape and thermoplastic panel material.

Specimen I.D.	CTE (10*E-5) in/in/Deg F	CTE Mismatch percent
Combat I.D. Tape	0.95	0
ABS-21	4.2-5.6	77-83
Boltaron 4330	2.5	62
Azdel	1.5	37

Although Azdel produced superior results, further investigations on these laminates were

discontinued, because Azdel is glass reinforced, not easily formable and cost higher than other thermoplastic panels.

ABS-21 was also discarded as there is a large CTE mismatch (77 to 83 percent) between thermoplastic and tape resulting in large amounts of wrinkles and excess panel warping.

Studies on Boltaron 4330 were continued. Boltaron specimens C-1 and C-2 were exposed to - 40° F for 26 hours. There was a dwell period of several days at room temperature after the completion of elevated temperature tests. Both specimens C-1 and C-2 produced a couple more wrinkles. The extreme temperatures programmed in the thermal cycles were expected to represent the temperatures in the field. We do not expect to see these extremes in one day. Therefore, the laboratory experiments were accelerated tests for the panels.

4. STUDIES ON 46 INCHES LONG AND 18 INCHES WIDE BOLTARON THERMOPLASTIC FLAT PANELS

Further studies on Boltaron thermoplastic flat panels were continued to study the effect of specimen size, CTE and bending stiffness on the performance of thermoplastic flat panels. The test matrix for 46 inches long and 18 inches wide specimens is presented in Table 4. This 46 inches represent the maximum length that could be used on a CIP insert and one of the purpose of this investigation was to study the maximum length effects on warping of panel and wrinkle formation by the tape. Here , bending stiffness is defined as the product of elastic modulus of material and area moment of inertia of cross section of flat panels. The bending stiffness controls the amount of warping during thermal cycles applied to the panel. The thermal cycle applied to 46 inches long and 18 inches wide thermoplastic flat panels is presented in Table 5.

Three types of Boltaron thermoplastic sheets, namely, Boltaron 1050-2079 Type I PVC, Boltaron 4050-2103 Type II PVC and Boltaron 4330 acrylic-polyvinyl chloride were investigated along with aluminum panels of same dimensions. The results of aluminum panels served as base line data to compare the performance of Boltaron thermoplastic panels. The photographs of Boltaron thermoplastic and aluminum panels are presented in Figs 1-A, 1-B, 2-A, 2-B , 3-A, 3-B, 4-A and 4-B at the end of thermal cycles. Results of test data on these flat panels is presented in Table 6. As expected, Boltaron 1050-2079 Type I PVC and aluminum panels performed well with both tan and green tapes.

4.1 Discussion and Conclusion of 46 Inches Long and 18 Inches Wide Flat Panel Tests

The wrinkle formation is due to the mismatch of coefficient of thermal expansions of tape and thermoplastic panel material. For Boltaron 1050-2079 Type I PVC , the mismatch of CTE was 42 percent. For this case, formation of wrinkles was the minimum. The mismatch of CTE for Boltaron 4050-2103 Type II PVC was 54 percent. The wrinkles increased due to the slight increase of CTE mismatch. For Boltaron 4330 acrylic PVC, CTE mismatch was 62 percent for which the maximum number of wrinkles were observed. The CTE mismatch for aluminum was 28 percent.

No wrinkles were observed in the case of aluminum panels.

The loss of adhesive bond strength, particularly at 160° F may also be another reason for formation of wrinkles. Due to loss of adhesive bond strength at 160° F, the tape may be separated from the panel. When the panel and tape were subjected to - 40° F temperature, the panel contracted more than the tape, resulting in formation of wrinkles.

Therefore, in order to eliminate wrinkle formation, it was absolutely necessary to eliminate large CTE mismatch between tape and thermoplastic material. Over the temperature range from 160° F to - 40° F, the adhesive should also retain substantial portion of its room temperature strength. Of the two temperatures, 160° F may be more critical for bond strength of adhesives.

In the case of flat panels, warping was observed. Warping in panels depends on modulus of material and moment of inertia of cross section of plastic. The modulus, moment of inertia and bending stiffness are presented in Table 7. Warping in flat panels was solely due to low bending stiffness compared to thermoformed corrugated panel inserts. When the panels were subjected to thermal cycles, due to mismatch of CTE of tape and thermoplastic material, bending moments were introduced in the panel. This caused the panel to bend and warp if panel bending stiffness was low. For example, for Boltaron 1050-2079, Type I PVC material the bending stiffness of flat panel was 230 inch-lbs. The bending stiffness increased to 40,800 inch-lbs for thermoformed corrugated panel insert. Therefore, the warping was completely eliminated in thermoformed corrugated panel inserts which will be reported in next section.

The length of flat panel had an effect on warping of panels. More warping was noticed in 46 inches long and 18 inches wide flat panels when compared to 24 inches long and 12 inches wide panels. The number of wrinkles also increased in long panels when compared to shorter panels.

5. STUDIES ON THERMOFORMED BOLTARON THERMOPLASTIC CORRUGATED PANEL INSERTS

Further studies were conducted to study the effect of panel size, shape, panel bending stiffness and CTE mismatch on Boltaron corrugated panel inserts' performance. One segment of corrugation of Boltaron panel insert is presented in Fig. 4-AA; and an equivalent segment of flat sheet is presented in Fig. 4-BB. These configurations were used to estimate the bending stiffness presented in Table 7. The bending stiffness of corrugated Boltaron panel was 178 times the bending stiffness of an equivalent flat panel. This prevented the warping of corrugated panels during thermal cycle tests due to mismatch of CTE between tape and Boltaron which was 42 percent for Boltaron 1050-2079, 54 percent for Boltaron 4050-2103 and 62 percent for Boltaron 4330. This CTE mismatch produced unequal forces on the tape and panel which caused the bending of the panels.

In the case of Aluminum, corrugated panel's bending stiffness was 176 times the bending stiffness of an equivalent flat aluminum panel (Table 7). However, there was no warping even in

the case of flat aluminum panel because the CTE mismatch between tape and aluminum was only 28 percent.

The test matrix for thermal cycle tests is presented in Table 8. The thermal cycle applied on these Boltaron corrugated panel inserts is presented in Table 9. The inserts were enclosed in the aluminum frame in order to prevent damage due to handling of the panels. All panels together were exposed to the same thermal cycle. Thermal cycle tests were conducted in a test chamber Fig. 5-AA in the Team Power Environmental Laboratory in building 7 at TARDEC by Cynthia S. Motzenbecker.

After applying 5 thermal cycles, the corrugated panel inserts were exposed for a week of solar heating tests in a special set up (Fig.5-AB1, Fig.5- AB2 and Fig. 5-AB3) in the Mobility Test Operations Laboratory in building 212 at TARDEC. These tests were conducted by Martin Rick Agnetti. Forty eight lamps simulated the solar heating on the panels mounted on side of the body of the HMMWV.

Two types of Boltaron corrugated panel inserts: Boltaron 1050-2079 Type I PVC and Boltaron 4050-2103 Type II PVC were investigated. In all 8 different inserts of different sizes and shapes were subjected to 5 thermal cycles presented in Table 9 followed by a week of solar heating tests.

The photographs for test specimens 1 through 8 after subjecting to 5 thermal cycles followed by the solar heating tests are presented in Figs. 5 through 12. The results of thermal cycle and solar heating test data is presented in Table 10.

In general, Boltaron 1050-2079 Type I PVC corrugated panels with tan color tape performed better than other panels. In fact, the Test Specimen 2 exhibited no wrinkles after 5 thermal cycles (Fig. 6-A through 6-E); and Test Specimen 7 exhibited no wrinkles after 5 thermal cycles and 2 wrinkles after 5 thermal cycles followed by a week of solar heating tests (Fig. 11-A through 11-F). Boltaron 4050-2079 Type II PVC developed the maximum of 8 wrinkles after 5 thermal cycles and 10 wrinkles after 5 thermal cycles followed by the solar heating tests.

The reasons for the formation of wrinkles are: First, CTE mismatch between tape and Boltaron material; Second, tape adhesive may not be retaining its room temperature strength over the temperature range from 160° F to - 40° F. Of the 2 temperatures, 160° F temperature is more critical than - 40° F, as adhesives behave poorly at higher temperature than at cryogenic temperatures.

Boltaron 1050-2079 Type I PVC had a CTE mismatch of 42 percent; Boltaron 4050-2103 Type II PVC had CTE mismatch of 54 percent. The aluminum had a CTE mismatch of 28 percent (Table 7).

It appears that the tape adhesive bond tolerates a mismatch of 28 percent as in the case of

aluminum even over a temperature range from 160° F to - 40° F (Table 6 and Fig.4-A and 4-B). There were no wrinkles in the aluminum flat panels.

The CTE mismatch of 42 percent in the case of Boltaron 1050-2079 Type I PVC and 54 percent in the case of Boltaron 4050-2103 Type II PVC were perhaps the reasons for formation of wrinkles in these panel inserts.

The panel temperatures achieved during a week of solar heating testing is presented in Table 11. Six hours of solar heating has produced a maximum of 130° F temperature on panel surface. In most cases, the addition of a week of solar heating to 5 thermal cycles produced an increase of 2 to 10 wrinkles. Here, once again CTE mismatch and deterioration of adhesive at 130° F are the reasons for producing additional wrinkles.

The effect of pure solar heating on the performance of panels was not assessed because the panels were subjected to thermal cycling testing prior to being subjected to the solar heating tests.

The size of corrugated panel insert had no effect either on warping of panel or on wrinkle formation. Long panels performed equally well as short panels. The shape of panels also had no effect on warping or wrinkle formation. Oblong panels performed as good as square panels. This is due to the increased bending stiffness of corrugated panels compared to flat panels.

The poor performance with green tape on Boltaron panels is difficult to explain (Figs. 7-A through 7-F, Figs. 8-A through 8-F, Figs. 9-A through 9-F, and Figs. 12-A through 12-F). Without a production buy of material, we were not able to color match the panels with the tape's color. As such, dark gray panels were used to simulate green and light gray panels were used to simulate tan. It was assumed that the dark grey panel would be the worst case over an actual green.

Some preliminary trials were made for pigmenting the thermoplastic with camouflage green and tan colors with complete success in the case of Boltaron 4330 acrylic PVC and Boltaron 1050 Type I PVC (Fig. 13 and Fig.14).

The following are the conclusions for corrugated panel inserts performance after thermal cycle and solar heating tests:

- o Geometry of corrugated Boltaron panel inserts was very stable after they were subjected to thermal cycle and solar heating tests. There was no warping of panels.
- o Boltaron 1050 - 2079 Type I PVC corrugated panel inserts with tan colored tape performed better than Boltaron 4050-2103 Type II PVC corrugated panel inserts.

6. RECOMMENDATIONS

Based on studies conducted here, following are the recommendations for future investigations:

- o A new tape should be developed with CTE mismatch between the tape and thermoplastic panel insert not to exceed 5 percent over a temperature range from - 40° F to 160° F.
- o A new adhesive should be developed for improving the bond strength between the new tape and Boltaron thermoplastic over a temperature range from - 40° F to 160° F.
- o There should be no excessive loss of adhesive bond strength between the tape and thermoplastic material particularly at 160° F.
- o Future laboratory tests should be conducted on pigmented Boltaron 1050-3719 tan color Type I PVC and Boltaron 1050-7344 green color Type I PVC thermoplastic panel inserts along with new tape having matching CTE.
- o The effect of humidity and moisture on the performance of the tape-panel bond and the formation of wrinkles was not investigated here. Field tests are being conducted at Fort Campbell, TN and they will include atmospheric humidity and moisture along with the temperature variation on the panel.
- o As an interim solution, pigmented Boltaron 1050-3719 tan color Type I PVC and Boltaron 1050-7344 green color type I PVC thermoplastics may be used along with the existing tan and green I. D. tapes for CIP inserts.

TABLE 1

COEFFICIENT OF THERMAL EXPANSION, MODULUS AND THICKNESSES OF THERMOPLASTIC MATERIALS									
MATERIAL	CTE 10 ⁻⁶ /IN./DEG F	MODULUS 1.0 ⁶ E-05 PSI	LENGTH FEET	WIDTH FEET	THICKNESS INCH	COMPANY I.D.	POC	PHONE #	
Combat I.D. Tape Mylar Polyester Film	0.95	5.55	L	3	0.001	Opticoat Associates	Smith	508 250 8115	
Existing Combat I.D. Panels- Aluminum	1.26-1.37	100	L	W	0.04	Alcoa			
Lexan 8000 Polycarbonate	3.46	2.5	8	4	0.12	G.E. Plastics	Bill Mills	810 351 8566	
Lexan 6000 Polycarbonate	3.75	3.25	8	4	0.12	G.E. Plastics	Bill Mills	810 351 8566	
Lexan 9034	3.75	3.4	8	4	0.12	G.E. Plastics	Bill Mills	810 351 8566	
Ultem 1613 Polyetherimide	2.65	3.6	8	4	0.125	G.E. Plastics	Bill Mills	810 351 8566	
Ultem 1668A Polyetherimide	2.65	3.35	8	4	0.125	G.E. Plastics	Bill Mills	810 351 8566	
Hyzod GP Polycarbonate	3.75	3.4	8	4	0.125	Sheffield Plastics	Cindy	800 628 5084	
ABS Centrux 833	7.1	2.3	8	4	0.125	Cadillac Plastics		810 358 5544	
ABS Magnum 4410	3.8	3.33	8	4	0.125	Royalite		800 388 7527	
ABS Lustran 456	5.3	1.45	8	4	0.125	Royalite		800 388 7527	

Table -1 (Continued)									
Material I.D.	CTE 10°E-05 IN./IN./DEG F	MODULUS 1.0°E-5 PSI	DIMENSIONS			COMPANY I.D.	POC	PHONE #	
			LENGTH FEET	WIDTH FEET	THICKNESS INCH				
ABS R12	4.2-5.6	3.1	8	4	0.125	Royalite		800 388 7527	
ABS R20	4.2-5.6	2.3	8	4	0.125	Royalite		800 388 7527	
ABS R21	4.2-5.6	2.3	8	4	0.125	Royalite		800 388 7527	
ABS S250	4.2-5.6	2.9	8	4	0.125	Royalite		800 388 7527	
ABS R26	4.2-5.6		8	4	0.125	Royalite		800 388 7527	
Acrylic/PVC DKE 400	4.0 - 5.0	3.2	8	4	0.125	Royalite		800 388 7527	
Acrylic/PVC DKE 450	4.0 - 5.0	3.4	8	4	0.125	Royalite		800 388 7527	
ABS/PVC R 59	4.6-5.9	2.7	8	4	0.125	Royalite		800 388 7527	
R 87/59	4.6-5.9	2.3	8	4	0.125	Royalite		800 388 7527	
Boltaron Acrylic Polyvinyl Chloride 4330	2.5	3.6	8	4	0.125	Cadillac Plastics		810 358 5544	
Boltaron 6530	2.5	3.1	8	4	0.125	Cadillac Plastics		810 358 5544	
Boltaron 1050	1.64	4	8	4	0.125	Cadillac Plastics		810 358 5544	

Table 1 (Continued)									
Material I.D.	CTE 10°E-05 IN./IN./DEG F	MODULUS 1.0° E-05 PSI	DIMENSIONS			THICKNESS INCH	COMPANY I.D.	POC	Phone #
			LENGTH FEET	WIDTH FEET					
Boltaron 4050	2.07	3	8	4		0.125	Cadillac Plastics		810 358 5544
Boltaron 4300	2.5	3	8	4		0.125	Cadillac Plastics		810 358 5544
Boltaron 4125	4.45	4	8	4		0.125	Cadillac Plastics		810 358 5544
Azdell 40 Percent Glass	1.5	8	8	4		0.125	Azdell Inc.	Phillip	810 356 3000
Azdell 30 Percent Glass	1.5	6.7	8	4		0.125	Azdell Inc.	Phillip	810 356 3000
Dupont XTC 025 R	1.6	1.2	1.3	1.3		0.125	Dupont Automotive Engineering Materials	Romano	810 583 8128
Ertalyte PET-P Polyester	3.3	4.6	8	4		0.125	Polymer Corporation	Overfield	610 320 6660

TABLE 2

TEST SPECIMEN FOR 24 INCH LONG, 12 INCH WIDE THERMOPLASTIC FLAT PANELS

SPECIMEN I.D	MATERIAL I.D	COLOR OF SPECIMEN	CAMBAT TAPE I.D.	CTE 10.E-05 IN. /IN/ DEG F	SPECIMEN DIMENSIONS		
					LENGTH INCH	WIDTH INCH	THICKNESS INCH
A-1	AZDEL	WHITE	TAN	1.5	24	12	0.108
A-2	AZDEL	WHITE	GREEN	1.5	24	12	0.108
B-1	ABS-21	BLACK	TAN	4.2-5.6	24	12	0.125
B-2	ABS-21	BLACK	GREEN	4.2-5.6	24	12	0.125
C-1	BOLTARON 4330	BLACK	TAN	2.5	24	12	0.125
C-2	BOLTARON 4330	BLACK	GREEN	2.5	24	12	0.125
D-1	BOLTARON 4330	BLACK	TAN	2.5	24	12	0.125
D-2	BOLTARON 4330	BLACK	GREEN	2.5	24	12	0.125
E-1	ABS-21	BLACK	TAN	4.2-5.6	24	12	0.125
E-2	ABS-21	BLACK	GREEN	4.2-5.6	24	12	0.125

TABLE 3
THERMAL CYCLE FOR PRELIMINARY LABORATORY TESTS
ON 24 INCH LONG AND 12 INCH WIDE THERMOPLASTIC FLAT PANELS

TEMPERATURE F DEGREES	TIME HOURS	TEMPERATURE RAMPING RATE F DEGREES/ MINUTE
72	0.25	
72 to 160	0.5	2.93
160	5	
160 to 72	0.5	2.93
72 to -40	1	1.87
-40	26	
-40 to 70	1	1.87

TABLE 4

TEST SPECIMEN MATRIX FOR 46 INCH LONG AND 18 INCH WIDE THERMOPLASTIC FLAT PANELS

MATERIAL I.D.	COLOR OF SPECIMEN	COMBAT TAPE I.D.	CTE 10.E-05 IN./IN/DEG F	SPECIMEN DIMENSIONS		
				LENGTH INCH	WIDTH INCH	THICKNESS INCH
BOLTARON 1050-2079 TYPE I PVC	DARK GREY	TAN	1.65	46	18	0.125
BOLTARON 1050-2079 TYPE I PVC	DARK GREY	GREEN	1.65	46	18	0.125
BOLTARON 4050-2103 TYPE II PVC	LIGHT GREY	TAN	2.07	46	18	0.125
BOLTARON 4050-2103 TYPE II PVC	LIGHT GREY	GREEN	2.07	46	18	0.125
BOLTARON 4330	BLACK	TAN	2.5	46	18	0.125
BOLTARON 4330	BLACK	GREEN	2.5	46	18	0.125
ALUMINUM	TAN CARC PAINT	TAN	1.26	46	18	0.04
ALUMINUM	GREEN CARC PAINT	GREEN	1.26	46	18	0.04

TABLE 5
THERMAL CYCLE FOR LABORATORY TESTS
ON 46 INCH LONG AND 18 INCH WIDE THERMOPLASTIC FLAT PANELS

TEMPERATURE F DEGREES	TIME HOURS	TEMPERATURE RAMPING RATE F DEGREES / MINUTE
73.4	24	
73.4 to -40	1	1.89
-40	24	
- 40 to 73.4	1	1.89
73.4 to 160	0.5	2.93
160	8	
160 to 73.4	0.5	2.93

TABLE 6

EXPERIMENTAL DATA ON THERMOPLASTIC FLAT PANELS
TEST PANEL SIZE 46 INCH LONG AND 18 INCH WIDE

MATERIAL I.D.	TAPE I.D.	CTE 10 ⁻⁶ E-05 IN/IN/F	THERMAL CYCLE COMPLETED	EXPERIMENTAL OBSERVATION
BOLTARON 1050-2079 TYPE I PVC DARK GREY	TAN	1.65	2 3	Only one wrinkle stretched across the width of tape and at the center of the panel Specimen lightly warped and should not be a major concern A few wrinkles at a few more places and warping remained the same
BOLTARON 1050-2079 TYPE I PVC DARK GREY	GREEN	1.65	2 3	No wrinkles and light warping A few wrinkles at a few places and slight increase in warping
BOLTARON 4050-2103 TYPE II PVC LIGHT GREY	TAN	2.07	2 3	6-7 wrinkles spread along the length and specimen lightly warped A large number of wrinkles at several places and warping of sheet also increased
BOLTARON 4050-2103 TYPE II PVC LIGHT GREY	GREEN	2.07	2 3	6-7 wrinkles spread along the length and specimen lightly warped A large number of wrinkles at several places and specimen warping increased
BOLTARON 4330	TAN	2.5	2 3	6-7 wrinkles spread along the length and specimen badly warped Maximum number of wrinkles at several places and specimen warping also increased
BOLTARON 4330	GREEN	2.5	2 3	8-9 wrinkles stretched along the length and specimen badly warped Maximum number of wrinkles at several places and maximum specimen warping

TABLE 6				
CONTINUED				
MATERIAL I.D.	TAPE I.D.	CTE 10 ⁻⁶ E-05 IN/IN/F	THERMAL CYCLES COMPLETED	EXPERIMENTAL OBSERVATION
ALUMINUM	TAN	1.26	2	No wrinkling and no warping
			3	Some areas of tape debonded but no wrinkles and no warping of sheet
ALUMINUM	GREEN	1.26	2	No wrinkles and no warping
			3	No wrinkles & no separation of tape and no warping of sheet
MYLAR POLYESTER TAPE	TAN & GREEN	0.95		

TABLE 7							
THERMAL AND STIFFNESS CHARACTERISTICS OF BOLTARON AND ALUMINUM SHEETS							
MATERIAL I.D.	INSERT CONFIGURATION	CTE	MISMATCH IN CTE OF INSERT AND TAPE	MODULUS	MOMENT OF INERTIA	BENDING STIFFNESS	
		IN/IN/DEG F	PERCENT	PSI	(INCH ⁴ E+4)	LBS-(INCH ⁴ E+2)	
		X 10 ⁵ E-05		X 10 ⁵ E+05	X 10 ⁴ E-04	X 10 ⁴ E+02	
COMBAT I.D. TAPE		0.95	0	4			
MYLAR POLYESTER TAPE							
BOLTARON 1050-2079 TYPE I PVC DARK GREY	FLAT	1.64	42	4	5.76	2.3	
BOLTARON 1050-2079 TYPE I PVC DARK GREY	THERMOFORMED	1.64	42	4	1020	408	
BOLTARON 4050-2103 TYPE II PVC LIGHT GREY		2.07	54	3	5.76	1.73	
BOLTARON 4050-2103 TYPE II PVC LIGHT GREY	THERMOFORMED	2.07	54	3	1020	306	
BOLTARON 4300	FLAT	2.5	62	3	5.76	1.73	
BOLTARON 4300	THERMOFORMED	2.5	62	3	1020	306	
ALUMINUM	FLAT	1.32	28	100	0.187	1.87	
ALUMINUM	FORMED	1.32	28	100	330	330	

TABLE 8

TEST SPECIMEN MATRIX FOR BOLTARON CORRUGATED PANEL INSERTS									
SPECIMEN I.D.	MATERIAL I.D.	COLOR OF SPECIMEN	COMBAT I.D. TAPE COLOR	CTE OF TAPE 10"E-05 IN/IN/F	CTE OF INSERT 10" E-05 IN/IN/F	SPECIMEN DIMENSIONS @			
						LENGTH INCH	WIDTH INCH		
1	BOLTARON 4050-2103 TYPE II PVC	LIGHT GREY	TAN	0.95	2.07	31.5	26.5		
2	BOLTARON 1050-2079 TYPE I PVC	DARK GREY	TAN	0.95	1.65	31.5	26.5		
3	BOLTARON 1050-2079 TYPE I PVC	DARK GREY	GREEN	0.95	1.65	31.5	26.5		
4	BOLTARON 4050-2103 TYPE II PVC	LIGHT GREY	GREEN	0.95	2.07	31.5	26.5		
5	BOLTARON 1050-2079 TYPE I PVC	DARK GREY	GREEN	0.95	1.65	39.5	15.5		
6	BOLTARON 1050-2079 TYPE I PVC	DARK GREY	TAN	0.95	1.65	39.5	15.5		
7	BOLTARON 1050-2079 TYPE I PVC	DARK GREY	TAN	0.95	1.65	58	12		
8	BOLTARON 1050-2079 TYPE I PVC	DARK GREY	GREEN	0.95	1.65	58	12		
NOTE:									
@ = THICKNESS OF ALL PANELS = 0.125 INCH									

TABLE 9
THERMAL CYCLE FOR LABORATORY TESTS
ON BOLTARON CORRUGATED PANEL INSERTS

TEMPERATURE F DEGREES	TIME HOURS	TEMPERATURE RAMPING RATE F DEGREES/MINUTE
72 (Ambient)	0.08	
72 to 160	0.5	2.93
160	8	
160 to -40	1.62	2.06
-40	24	
-40 to 72	1.12	1.67

TABLE 10					
EXPERIMENTAL DATA FOR BOLTARON CORRUGATED PANEL INSERTS					
SPECIMEN	MATERIAL	TAPE	THERMAL	SOLAR	EXPERIMENTAL
I.D.	I.D.	I.D.	CYCLES	HEATING	OBSERVATION
			COMPLETED	COMPLETED	
1	BOLTARON 4050-2103	TAN	1	0	NO WRINKLES
	TYPE II PVC		2	0	NO WRINKLES
	LIGHT GREY		3	0	3 WRINKLES
			4	0	3 WRINKLES
			5	0	7 WRINKLES
			5	30 HOURS	9 WRINKLES
2	BOLTARON 1050-2079	TAN	1		NO WRINKLES
	TYPE I PVC		2		NO WRINKLES
	DARK GREY		3		NO WRINKLES
			4		NO WRINKLES
			5		NO WRINKLES
3	BOLTARON 1050-2079	GREEN	1		NO WRINKLES
	TYPE I PVC		2		1 WRINKLE
	DARK GREY		3		3 WRINKLES
			4		4 WRINKLES
			5		4 WRINKLES
4	BOLTARON 4050-2103	GREEN	1		NO WRINKLES
	TYPE II PVC		2		2 WRINKLES
	LIGHT GREY		3		4 WRINKLES
			4		7 WRINKLES
			5		8 WRINKLES
			5	30 HOURS	10 WRINKLES
5	BOLTARON 1050-2079	GREEN	1		NO WRINKLES
	TYPE I PVC		2		3 WRINKLES
	DARK GREY		3		3 WRINKLES
			4		3 WRINKLES
			5		3 WRINKLES
					8 WRINKLES
6	BOLTARON 1050-2079	TAN	1		NO WRINKLES
	TYPE I PVC		2		4 WRINKLES
	DARK GREY		3		6 WRINKLES
			4		6 WRINKLES
			5		6 WRINKLES
			5	30 HOURS	16 WRINKLES
7	BOLTARON 1050-2079	TAN	1		NO WRINKLES
	TYPE I PVC		2		NO WRINKLES
	DARK GREY		3		NO WRINKLES
			4		NO WRINKLES
			5		NO WRINKLES
			5	30 HOURS	2 WRINKLES

TABLE 10 CONTINUED					
8	BOLTARON 1050-2079	GREEN	1		2 WRINKLES
	TYPE I PVC		2		8 WRINKLES
	DARK GREY		3		8 WRINKLES
			4		8 WRINKLES
			5		10 WRINKLES
			5	30 HOURS	19 WRINKLES

TABLE 11
 PANEL TEMPERATURES ACHEIVED DURING 30 HOUR SOLAR HEATING
 OF BOLTARON CORRUGATED PANEL INSERTS

TEST TIME	AMBIENT TEMPERATURE	SOLAR LOAD	EQUIVALENT SOLAR HEATING W/MSQ	AVERAGE PANEL TEMPERATURE DEGREE F
	DEGREE F	W/MSQ	W/MSQ	DEGREE F
0:00	95	505	407	97
1:00	101	730	632	103
2:00	106	915	837	111
3:00	110	1040	987	119
4:00	116	1120	1086	125
5:00	116	1120	1086	127
6:00	120	1040	987	130

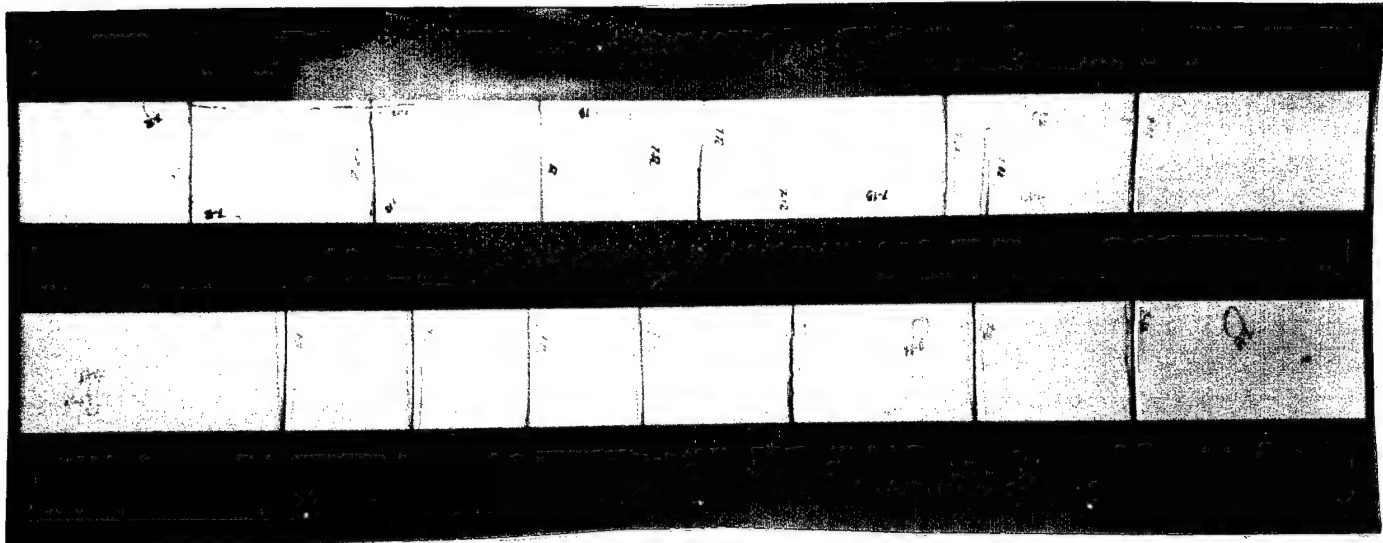


Fig. 1-A Boltaron 1050-2079 Type I PVC Thermoplastic Flat Sheet (46 inch x 18 inch)
with Tan Colored Tape

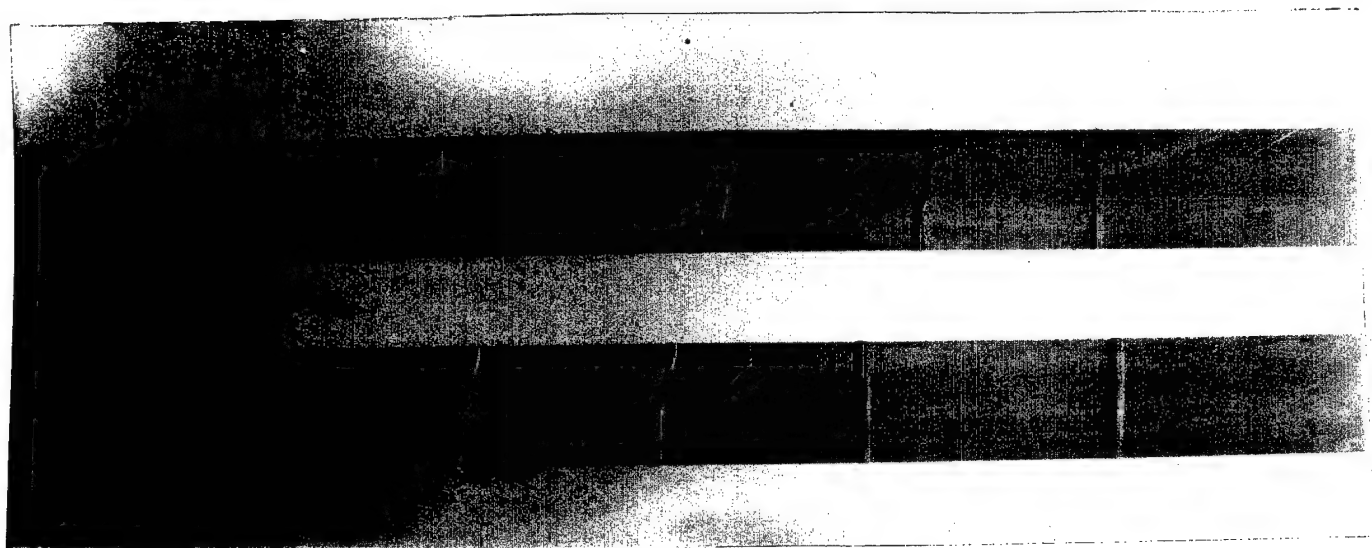


Fig. 1-B Boltaron 1050-2079 Type I PVC Thermoplastic Flat Sheet (46 inch x 18 inch)
with Green Colored Tape



Fig. 2-A Boltaron 4050-2103 Type II PVC Thermoplastic Flat Sheet (46 inch x 18 inch)
with Tan Colored Tape

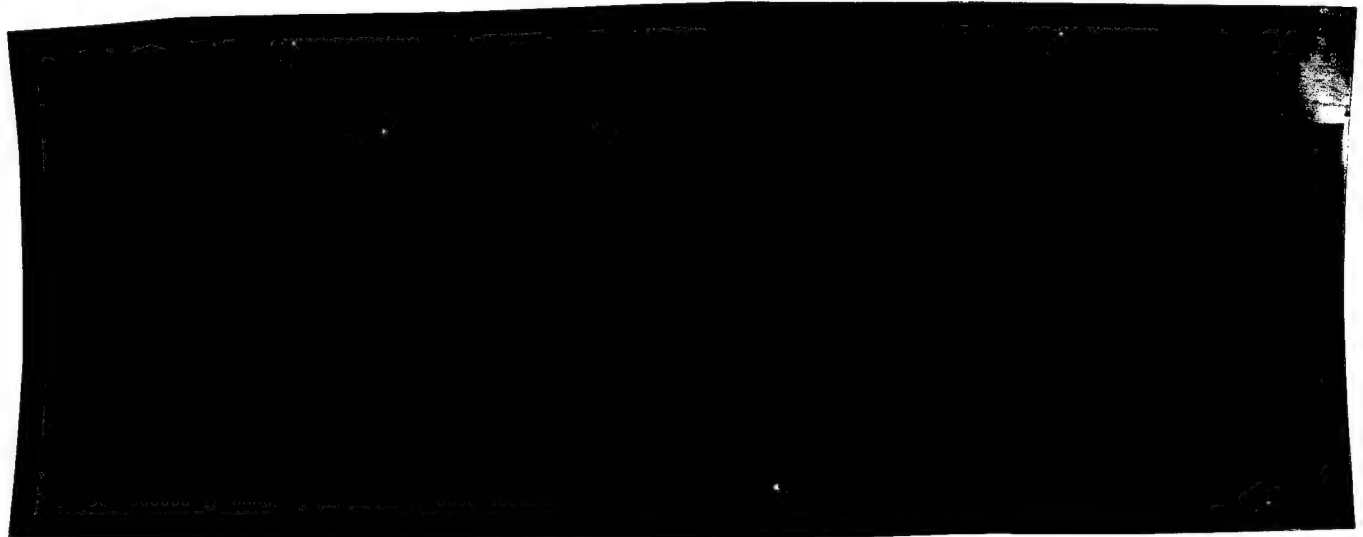


Fig. 2-B Boltaron 4050-2103 Type II PVC Thermoplastic Flat Sheet (46 inch x 18 inch)
with Green Colored Tape

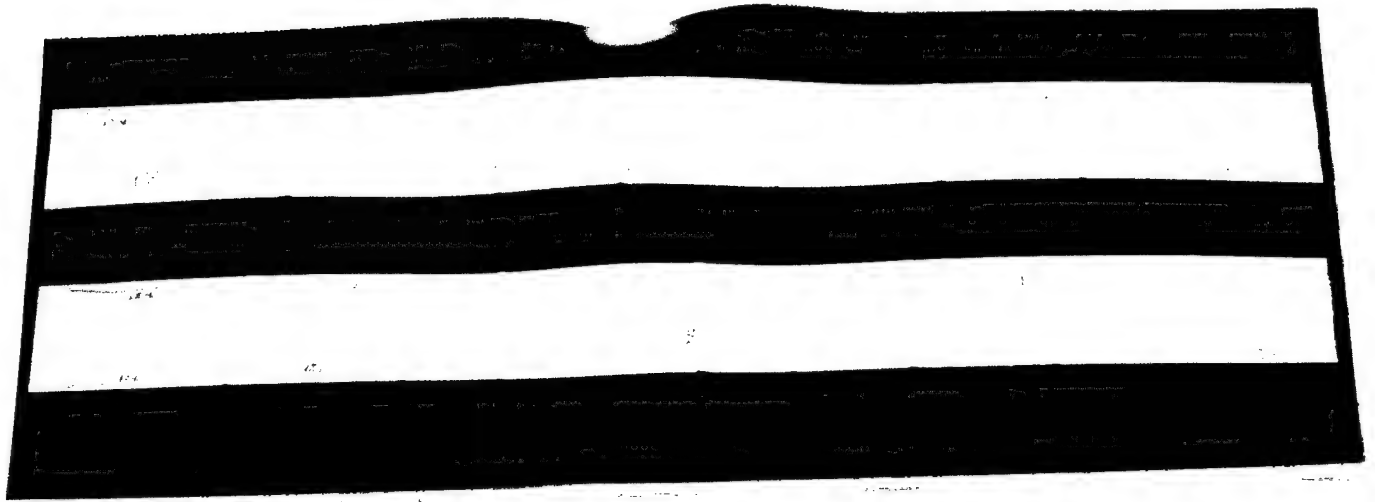


Fig.3-A Boltaron 4330 Acrylic/PVC Thermoplastic Flat Sheet (46 inch x 18 inch)
with Tan Colored Tape



Fig. 3-B Boltaron 4330 Acrylic/PVC Thermoplastic Flat Sheet (46 inch x 18 inch)
with Green Colored Tape

Fig.4-A Aluminum Flat Sheet (46 inch x 18 inch) with Tan Colored Tape

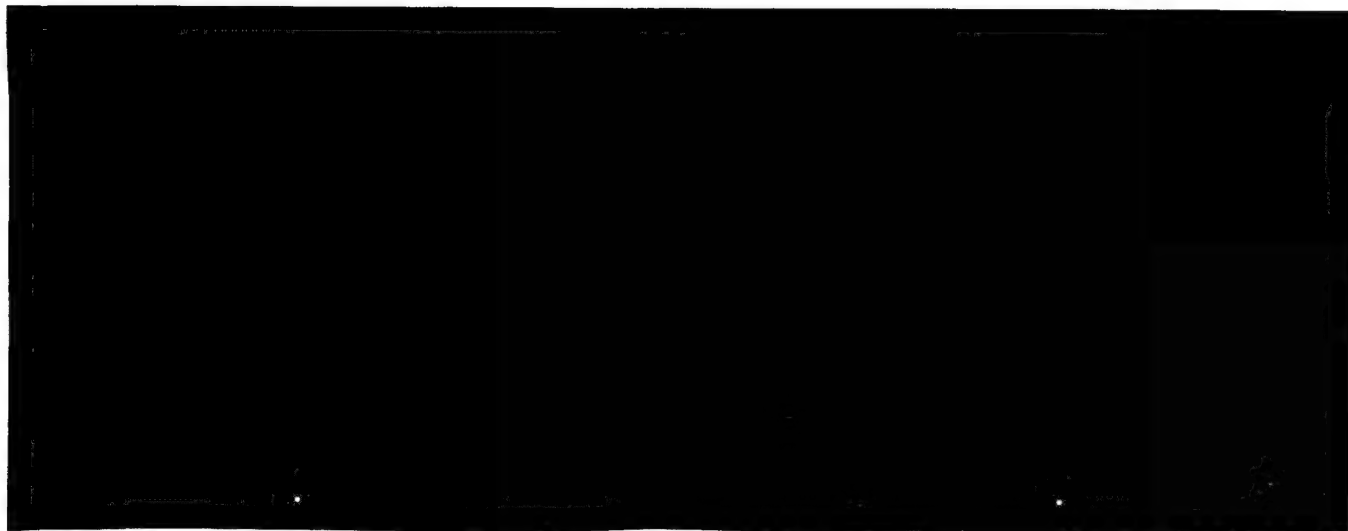


Fig. 4-B Aluminum Flat Sheet (46 inch x 18 inch) with Green Colored Tape

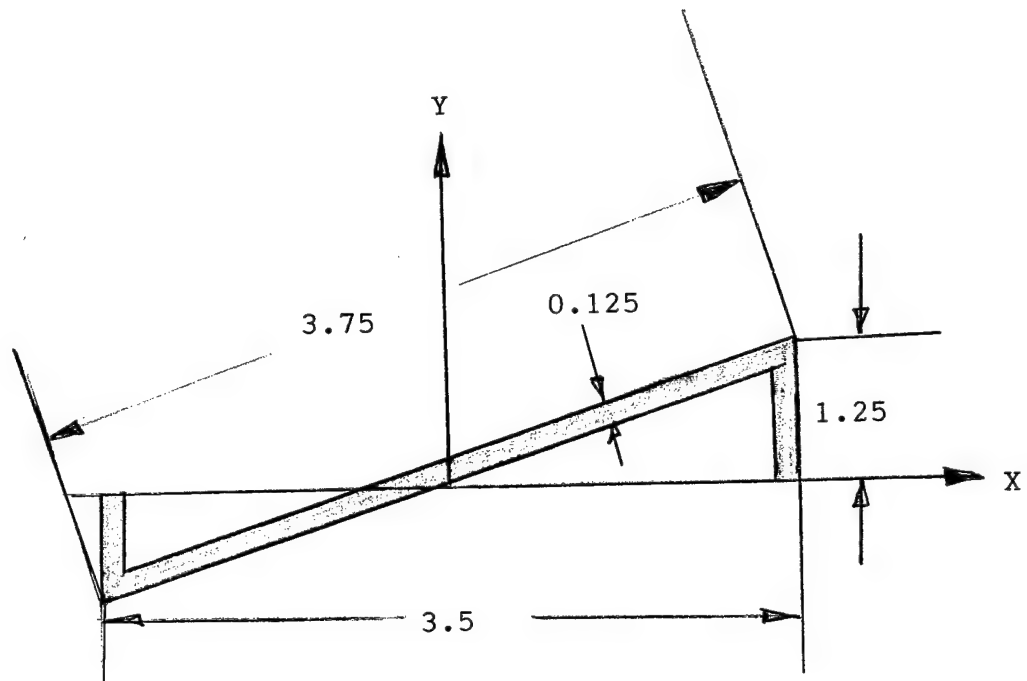


Fig. 4-AA Thermoformed Boltaron Thermoplastic Corrugated Sheet Segment

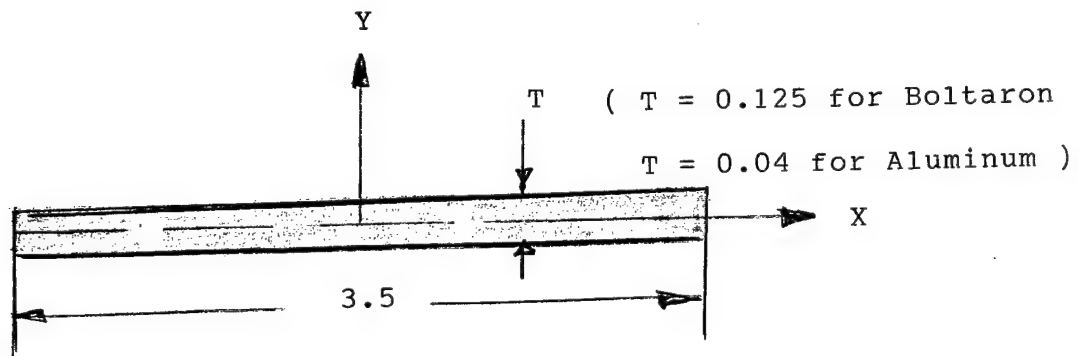


Fig. 4-BB Boltaron Thermoplastic Flat Sheet Segment

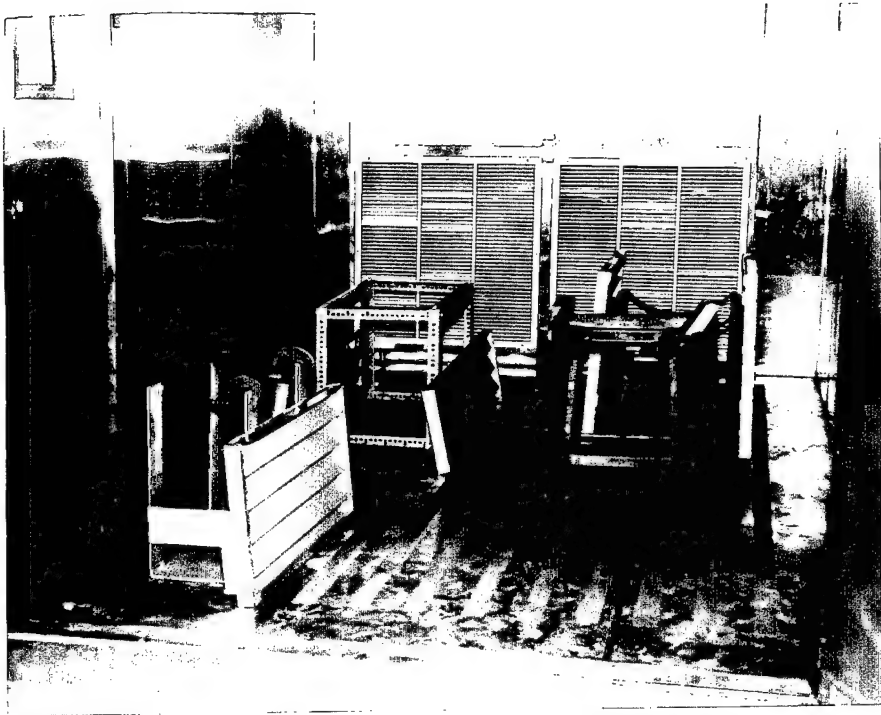


Fig. 5-AA Thermal Cycle Test Chamber



Fig. 5- AB1 Solar Heating Test Set Up

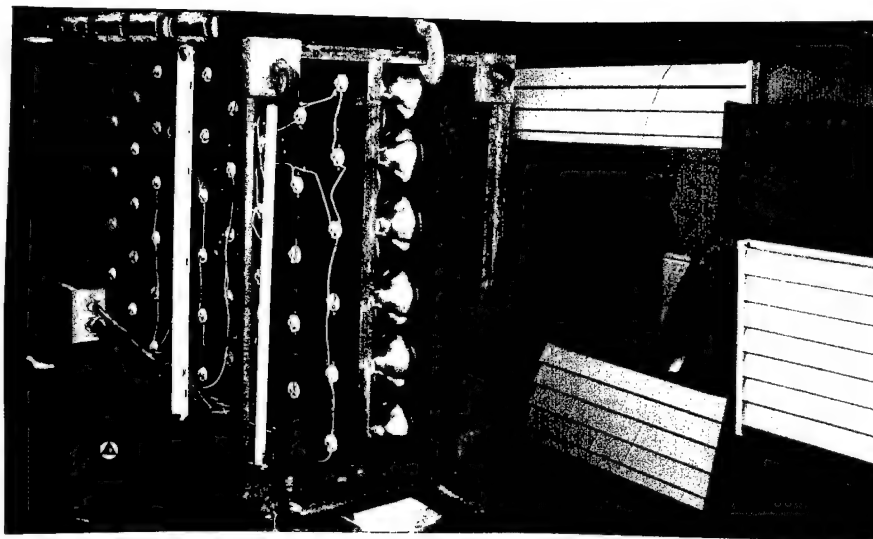


Fig. 5 AB2 Solar Heating Test Set Up

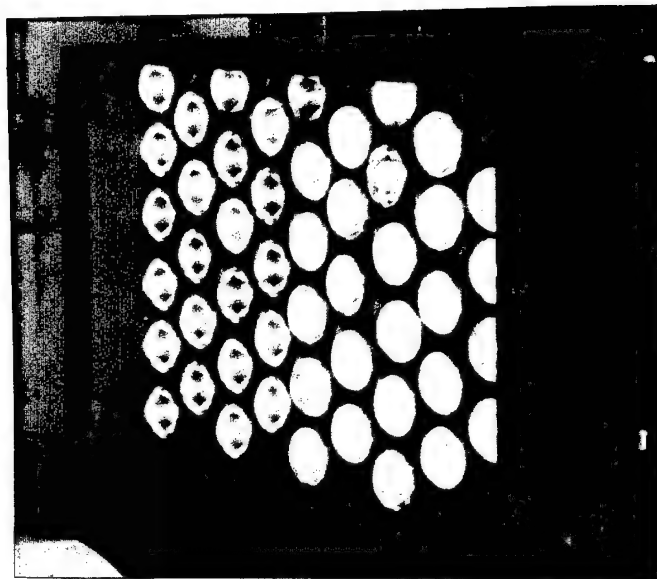


Fig. 5- AB3 Solar Heating Lamps

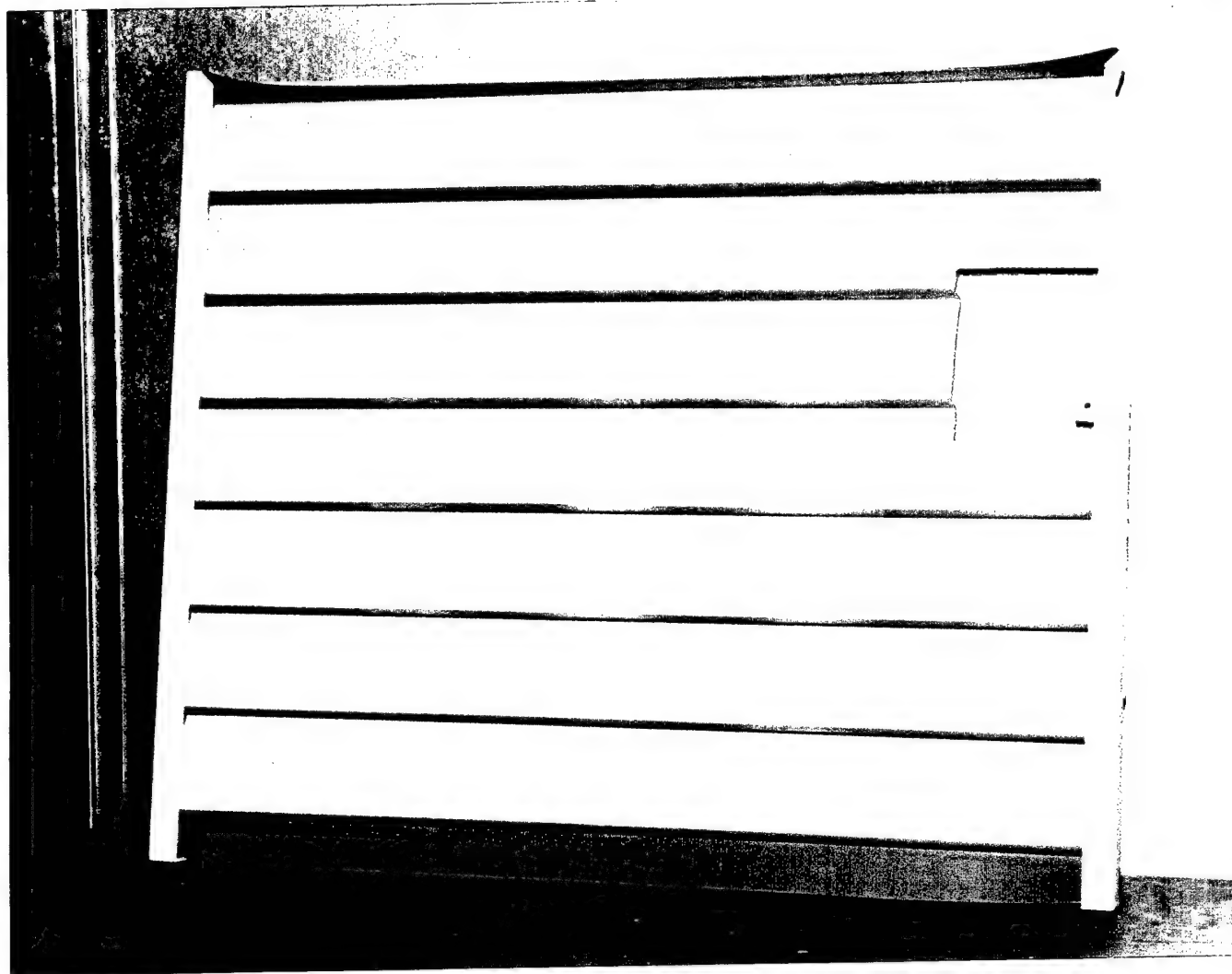


Fig.5-A Test Specimen Insert # 1 at the end of First Thermal Cycle

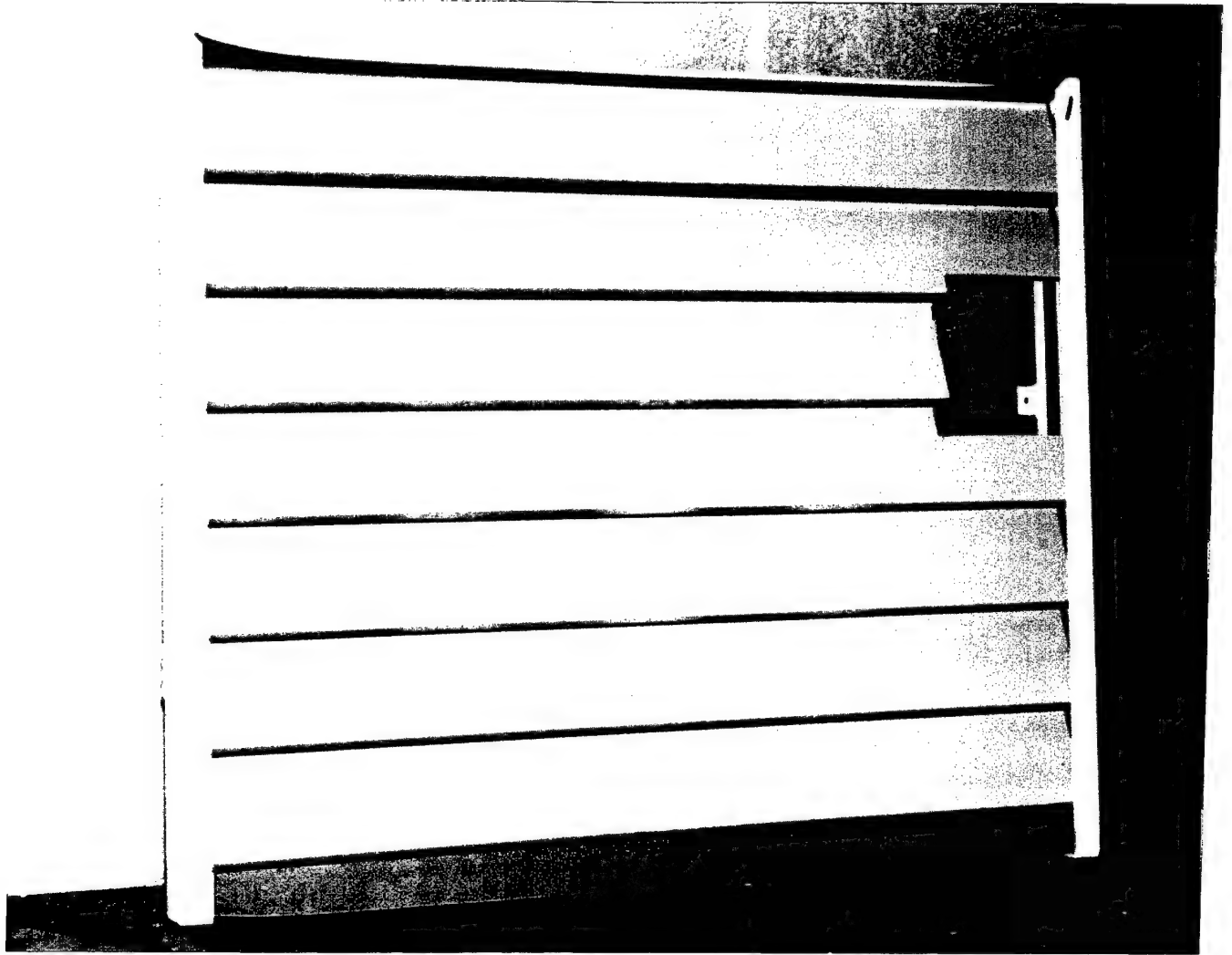


Fig.5-B Test Specimen Insert # 1 at the End of Second Thermal Cycle

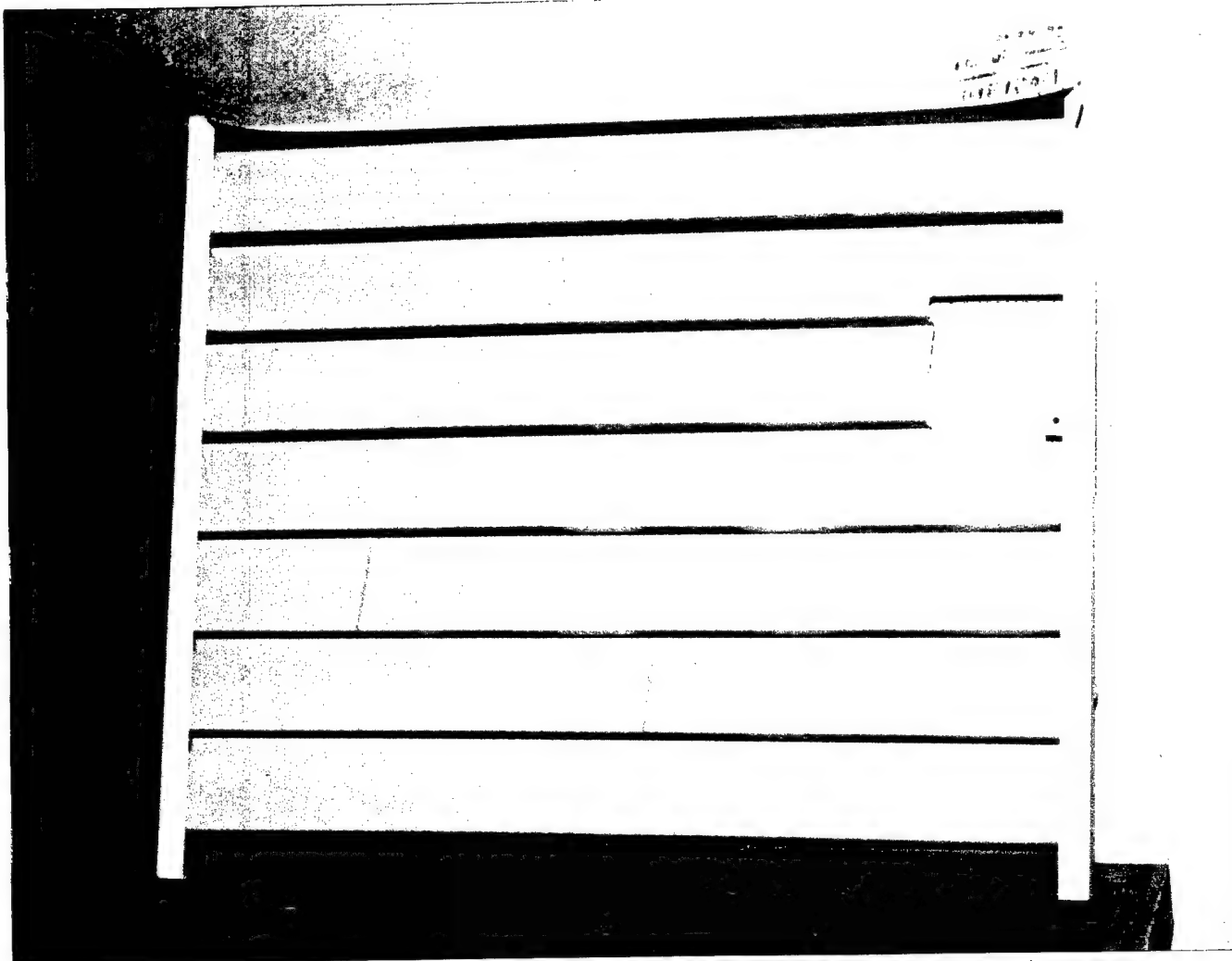


Fig.5-C Test Specimen Insert # 1 at the End of Third Thermal Cycle

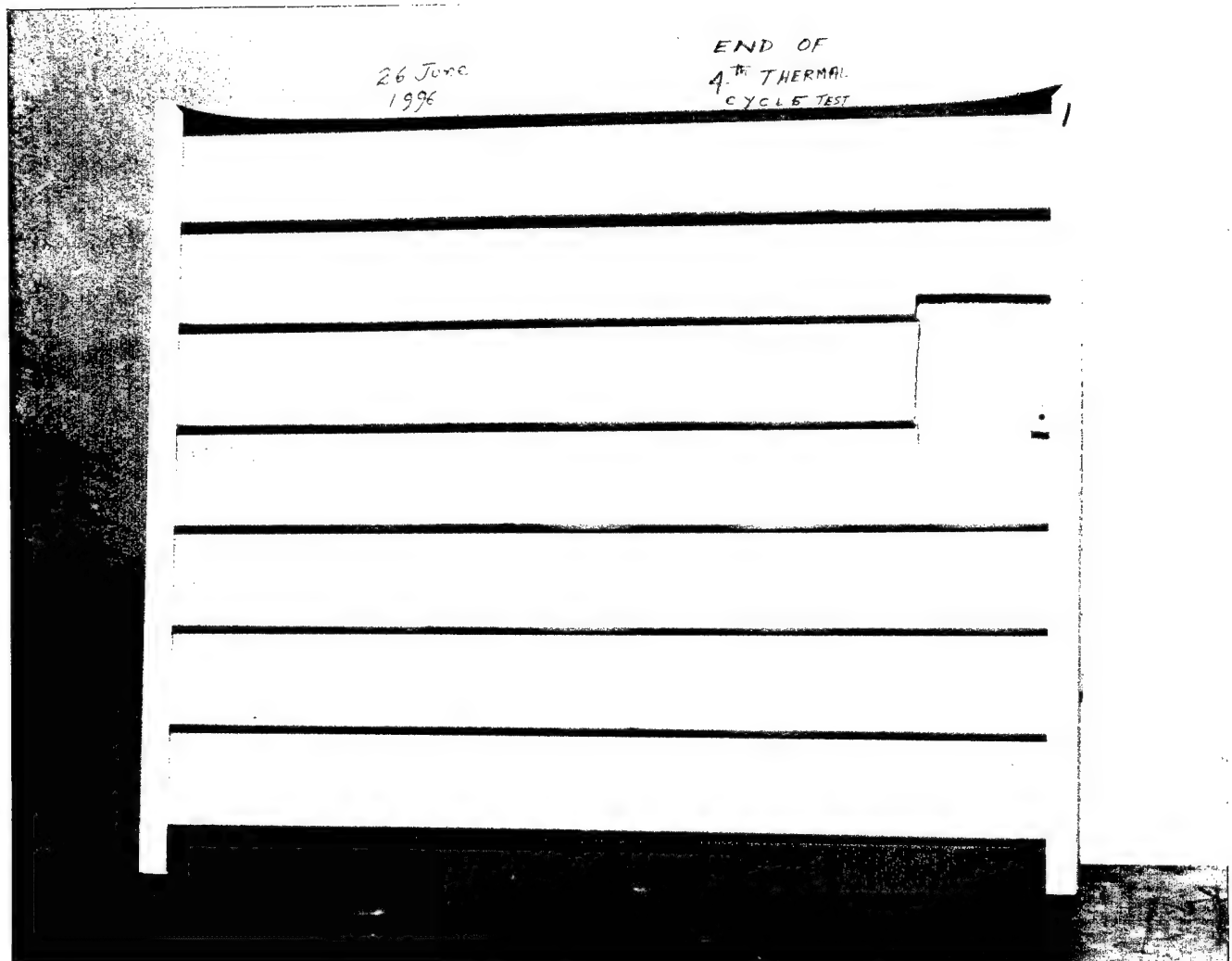


Fig.5-D Test Specimen Insert # 1 at the End of Fourth Thermal Cycle

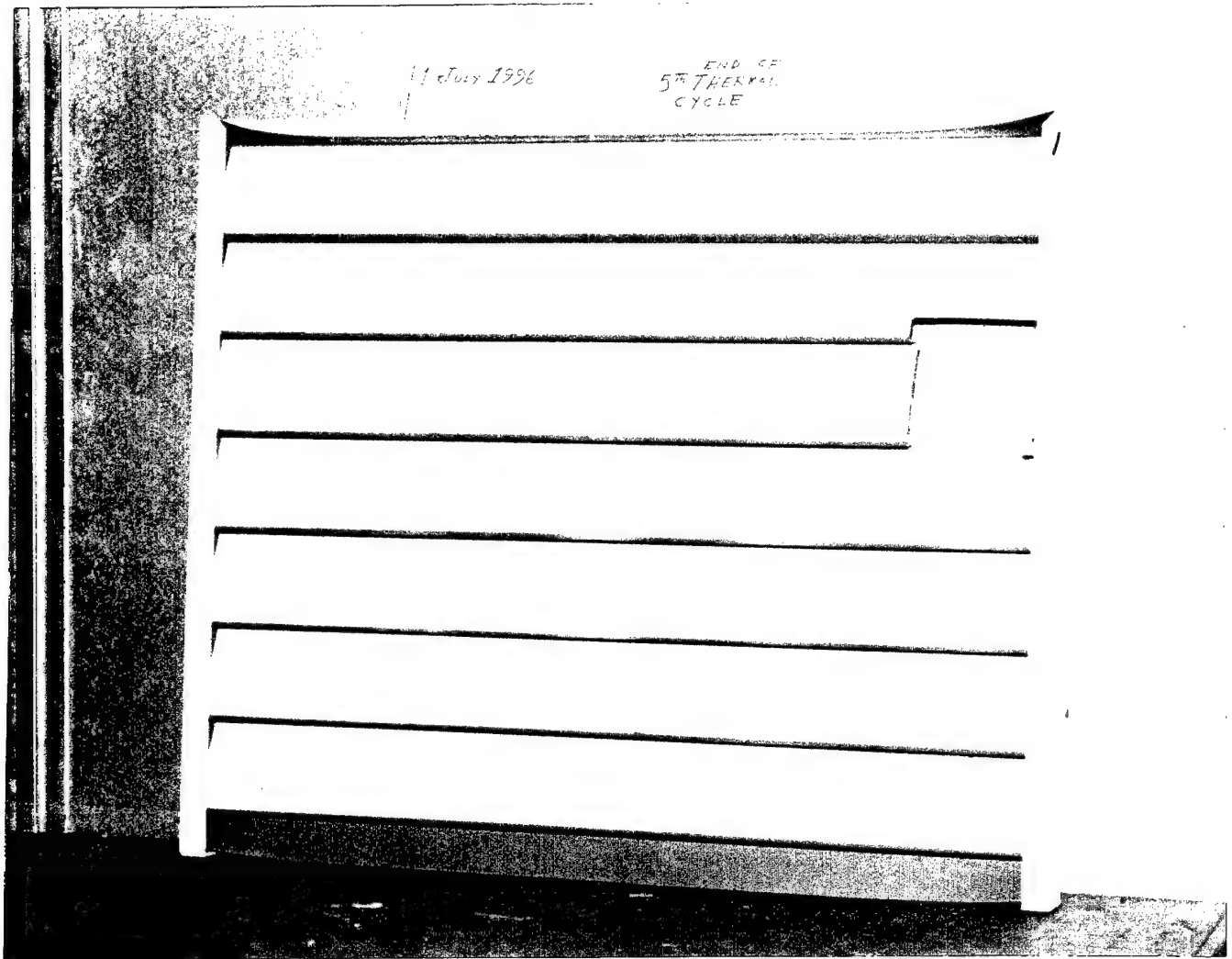


Fig.5-E Test Specimen Insert # 1 at the End of Fifth Thermal Cycle



Fig. 5-F Test Specimen Insert # 1 at the End of 30 Hours of Solar Heating

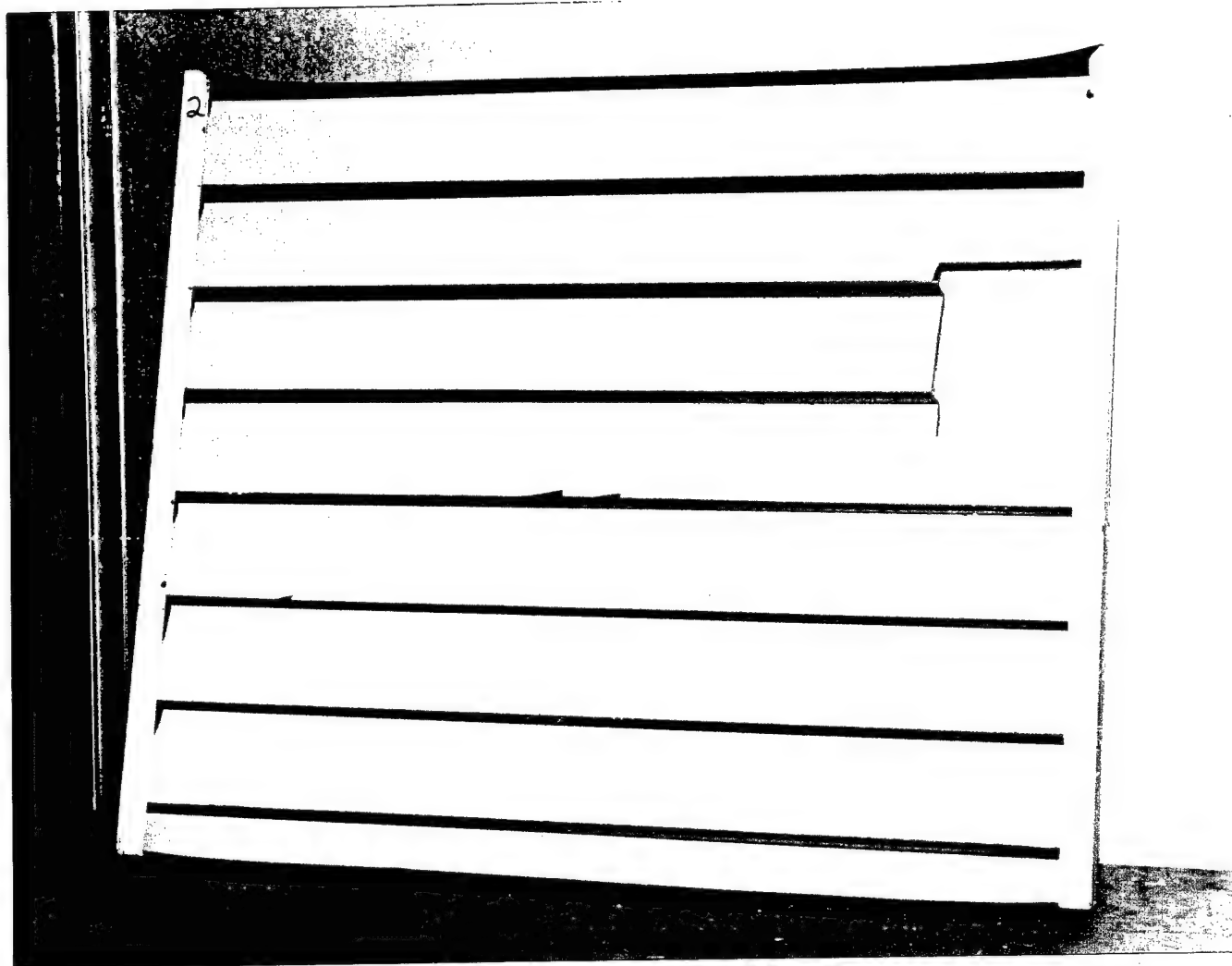


Fig.6-A Test Specimen Insert # 2 at the End of First Thermal Cycle

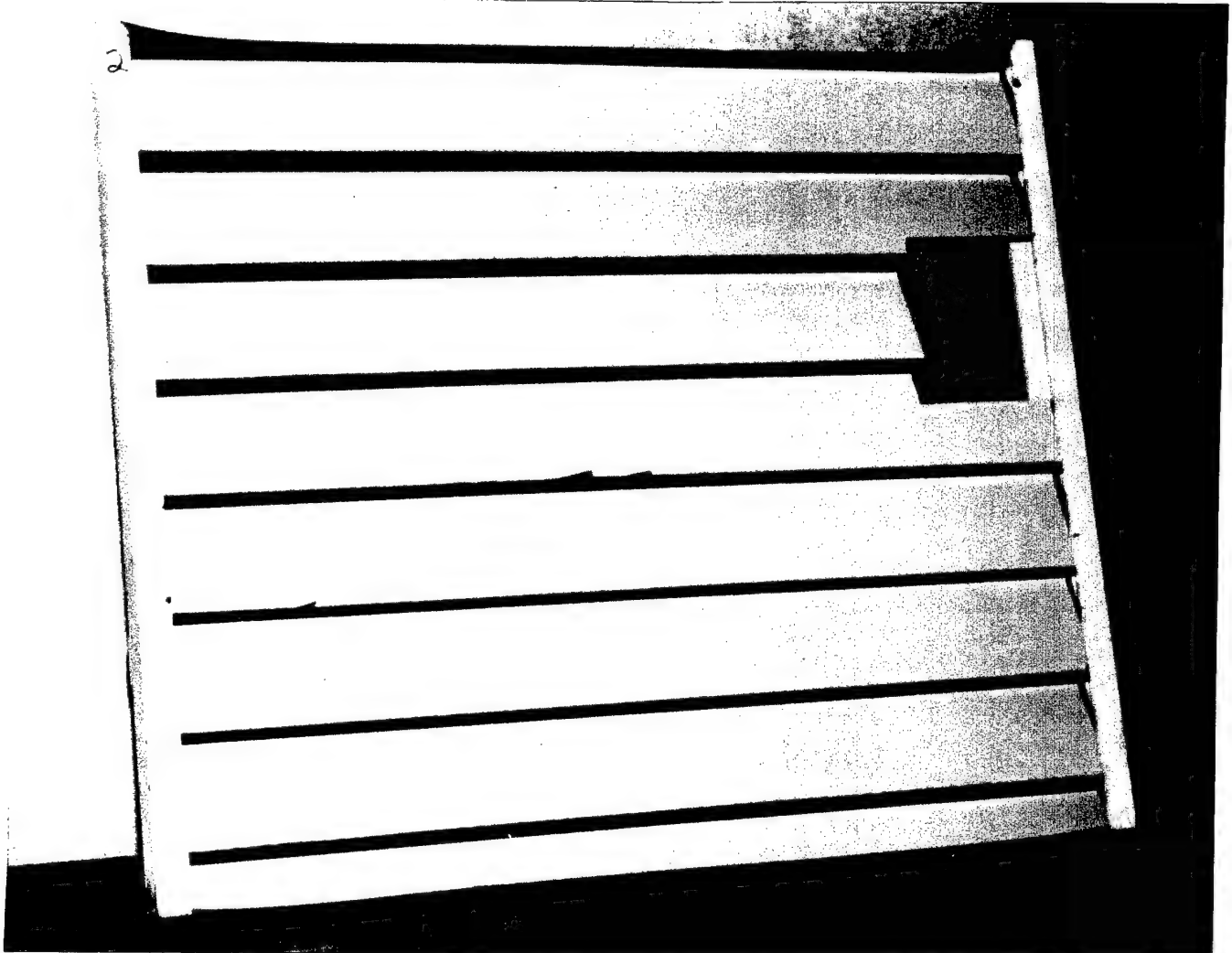


Fig.6-B Test Specimen Insert # 2 at the End of Second Thermal Cycle

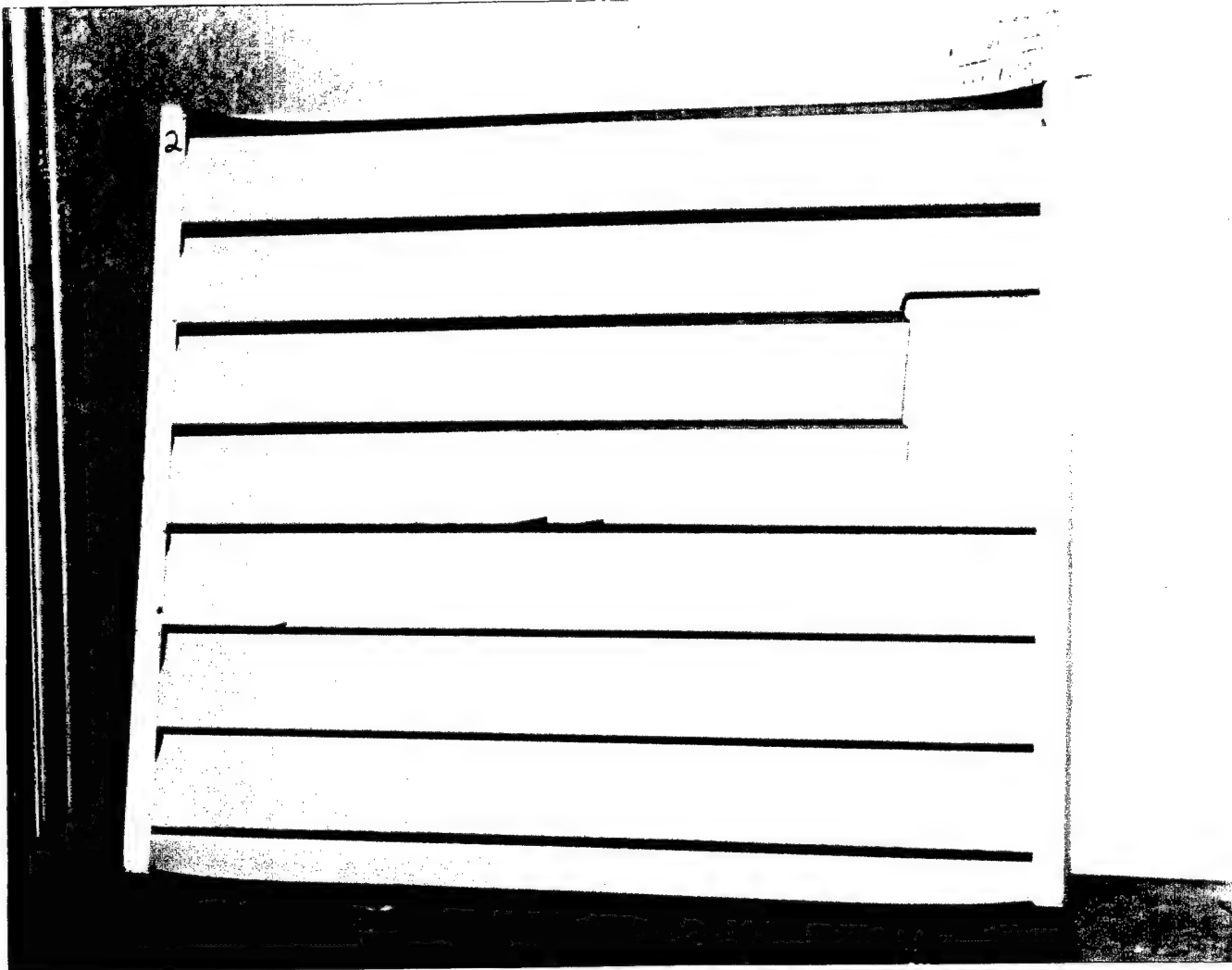


Fig.6-C Test Specimen Insert # 2 at the End of Third Thermal Cycle

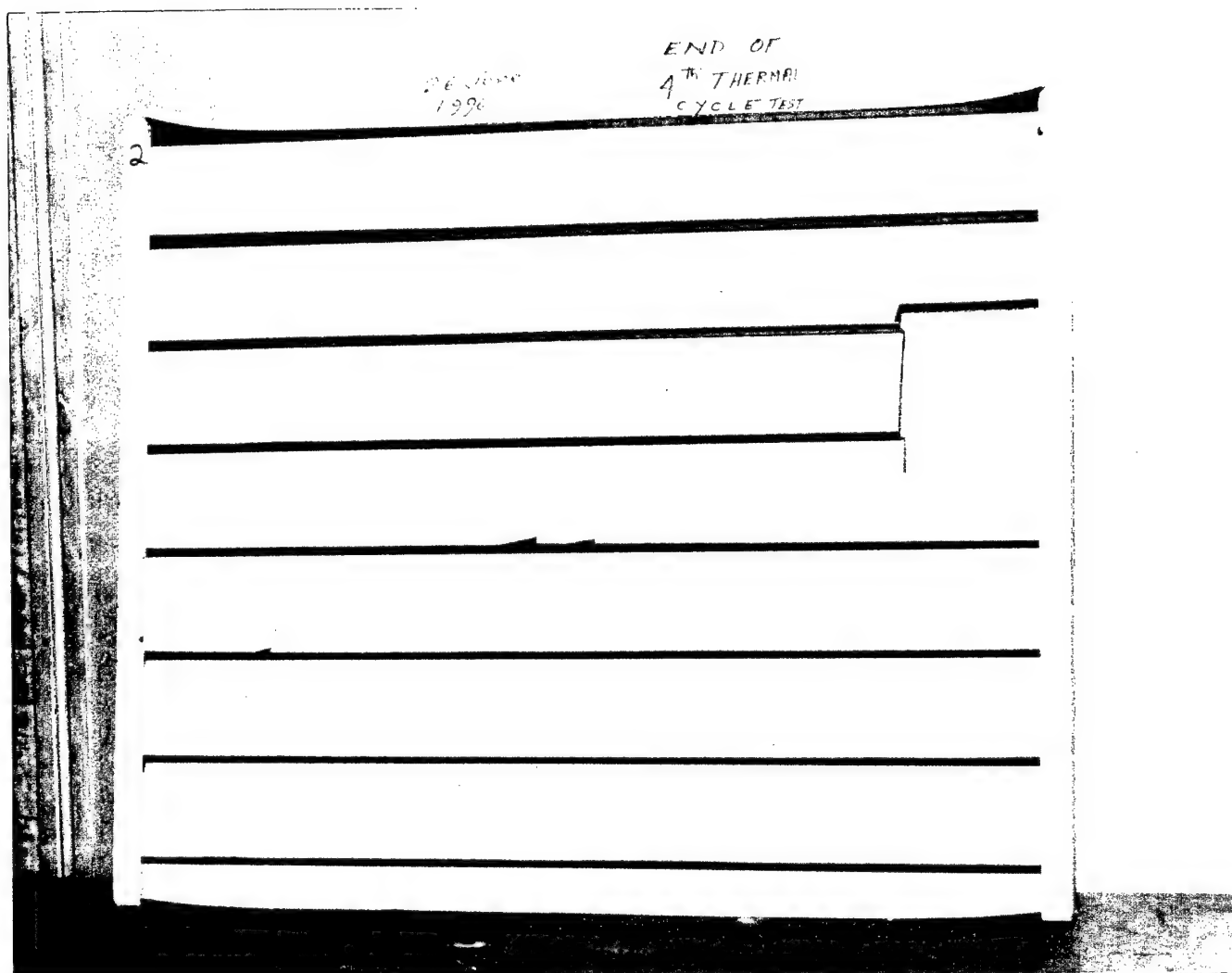


Fig.6-D Test Specimen Insert # 2 at the End of Fourth Thermal Cycle

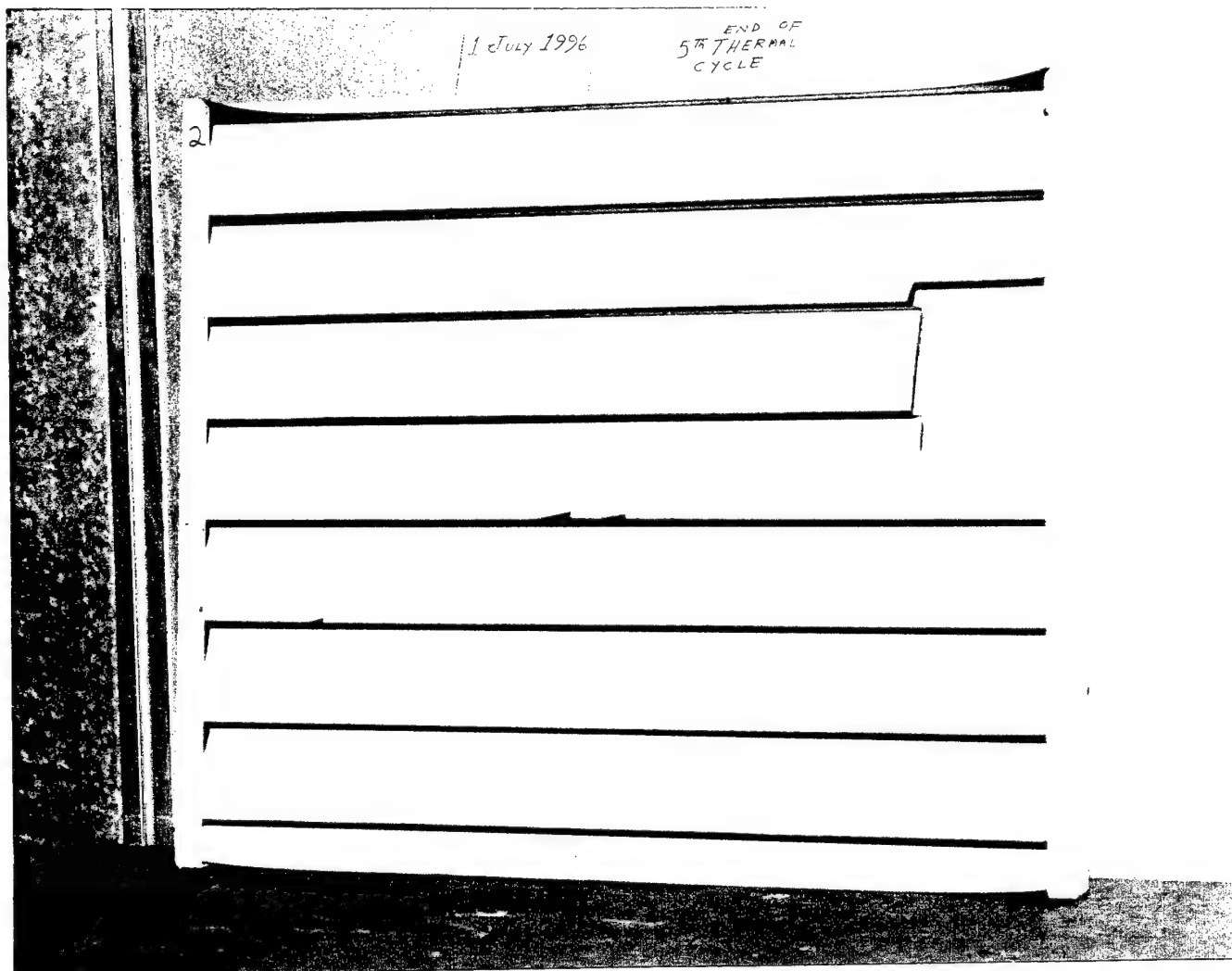


Fig.6-E Test Specimen Insert # 2 at the End of Fifth Thermal Cycle

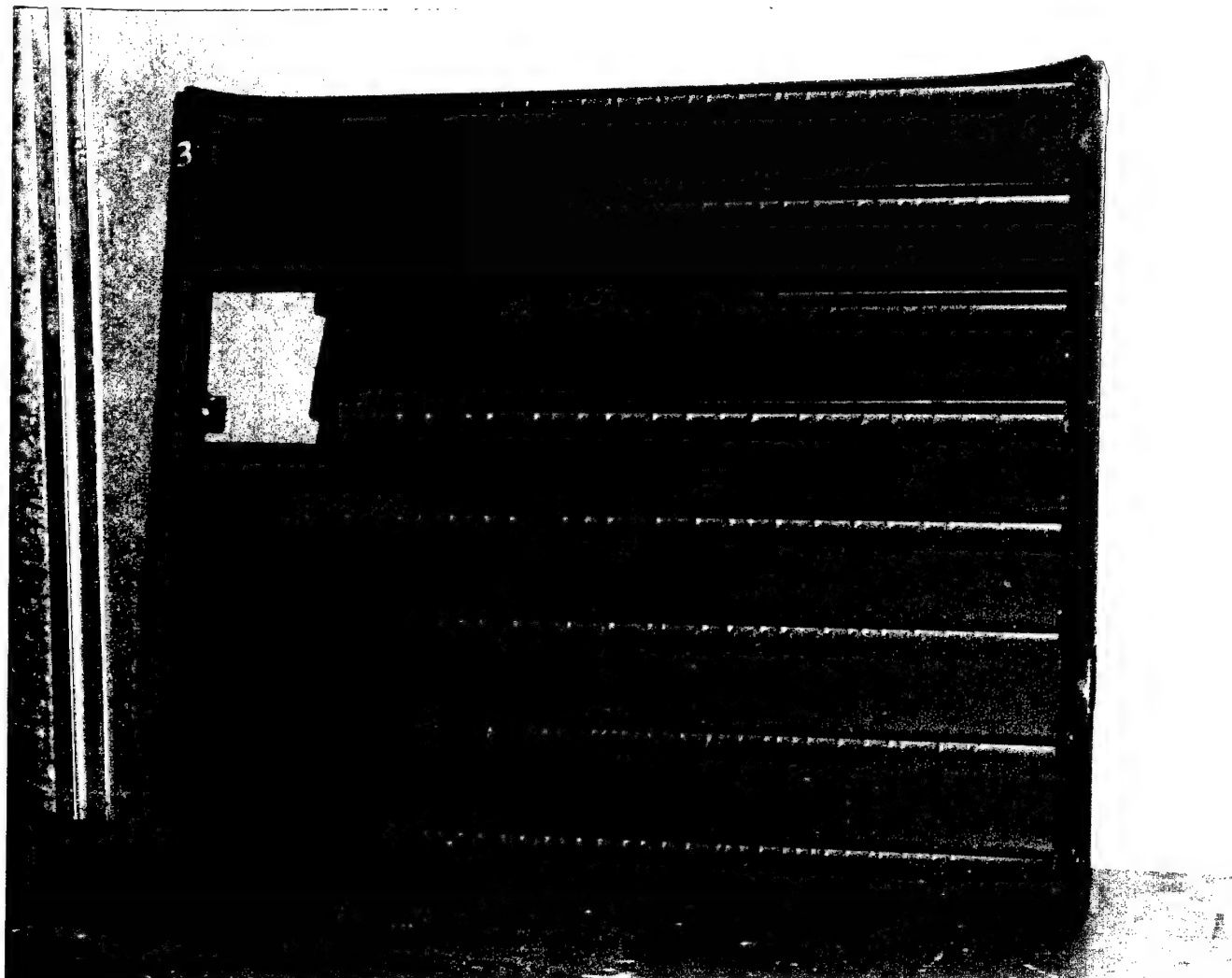


Fig. 7-A Test Specimen Insert # 3 at the End of First Thermal Cycle

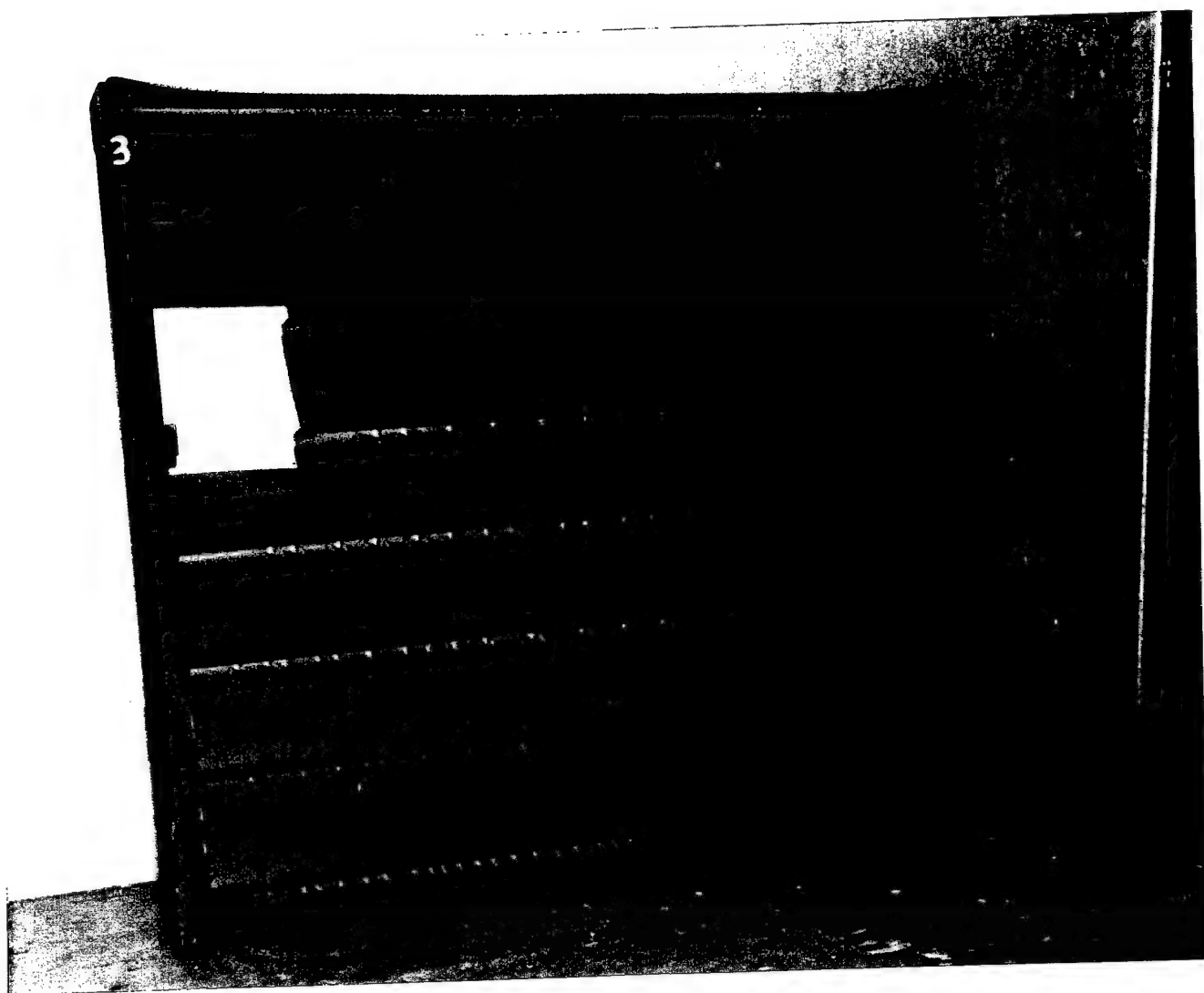


Fig. 7-B Test Specimen Insert # 3 at the End of Second Thermal Cycle

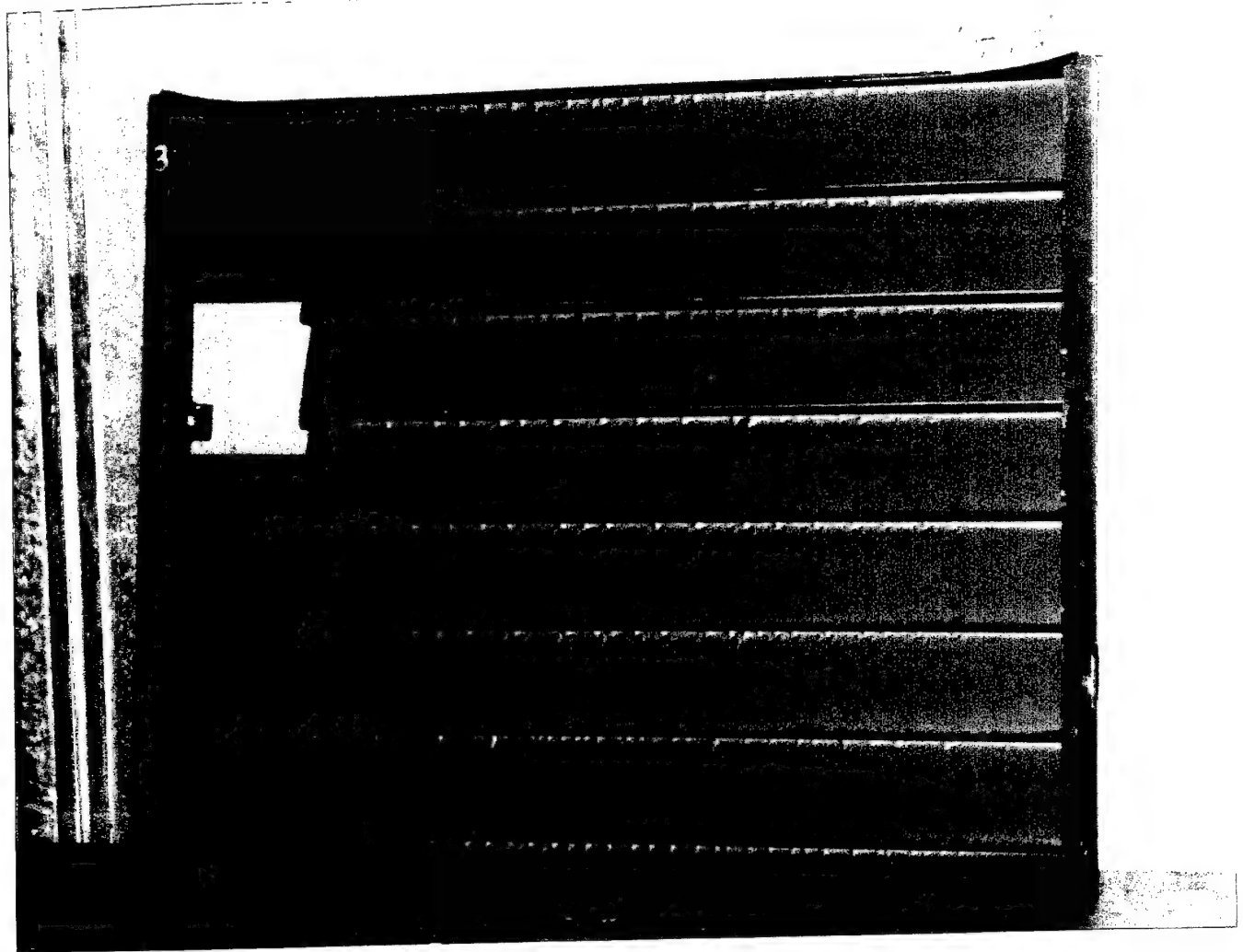


Fig. 7-C Test Specimen Insert # 3 at the End of Third Thermal Cycle

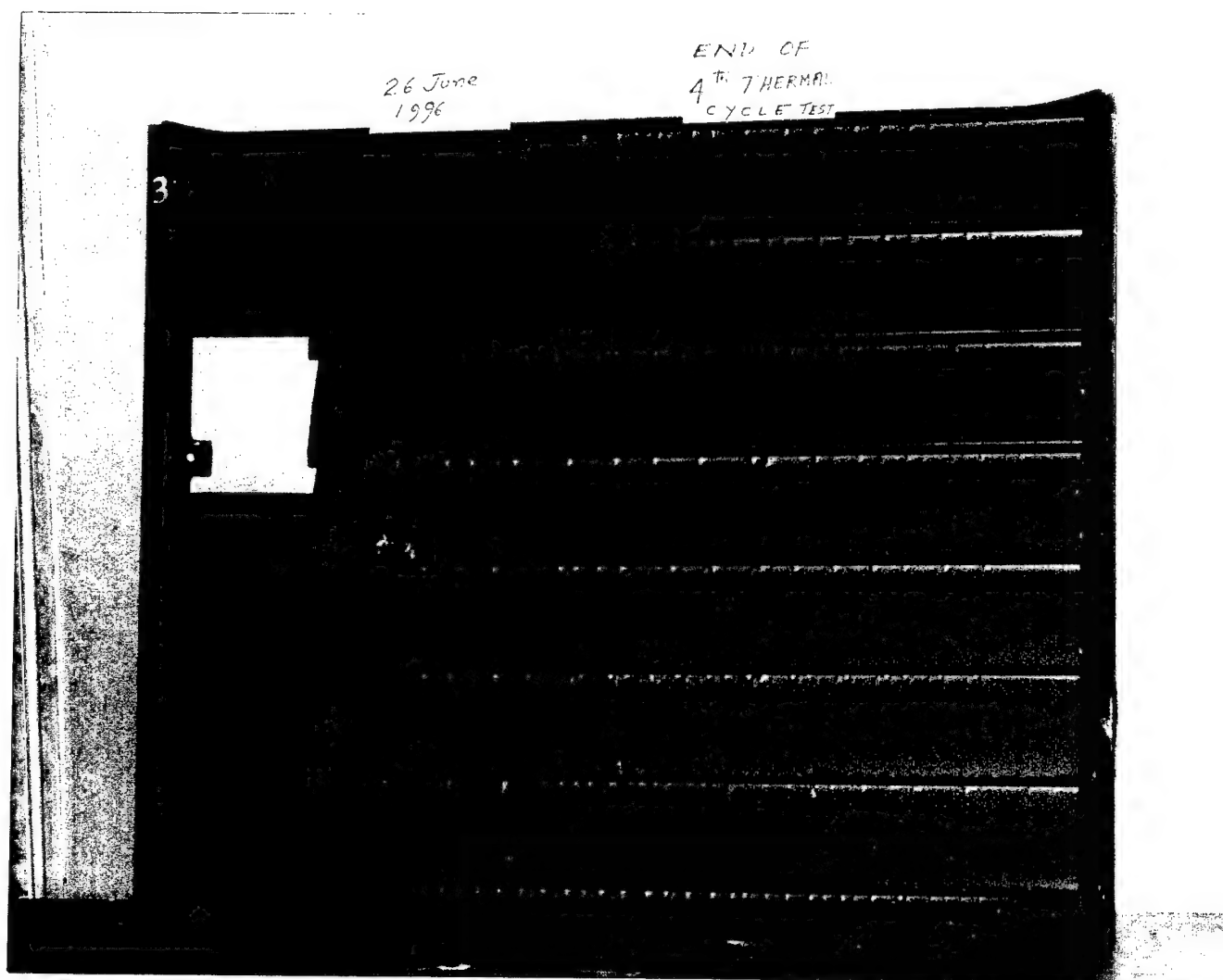


Fig. 7-D Test Specimen Insert # 3 at the End of Fourth Thermal Cycle

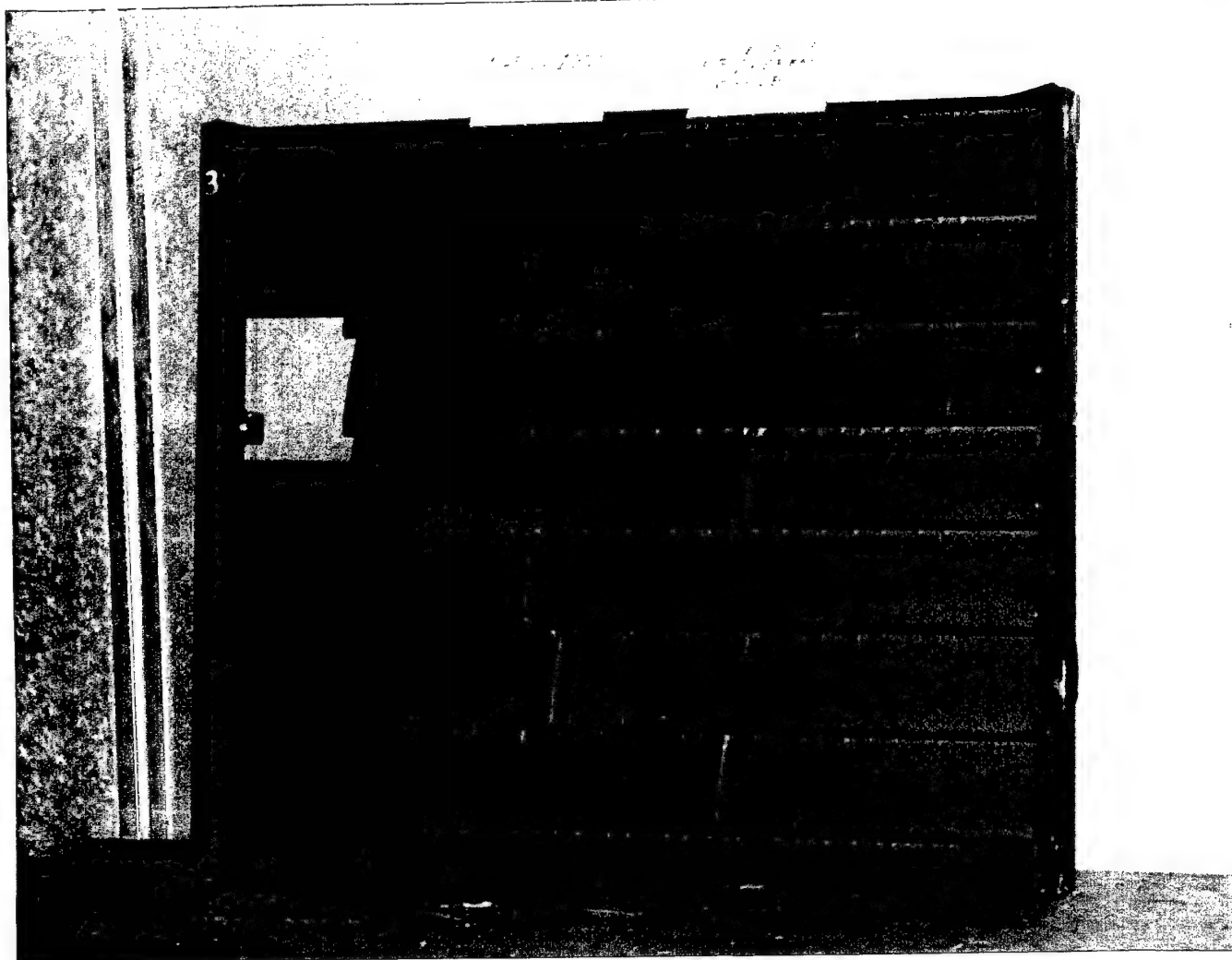


Fig. 7-E Test Specimen Insert # 3 at the End of Fifth Thermal Cycle

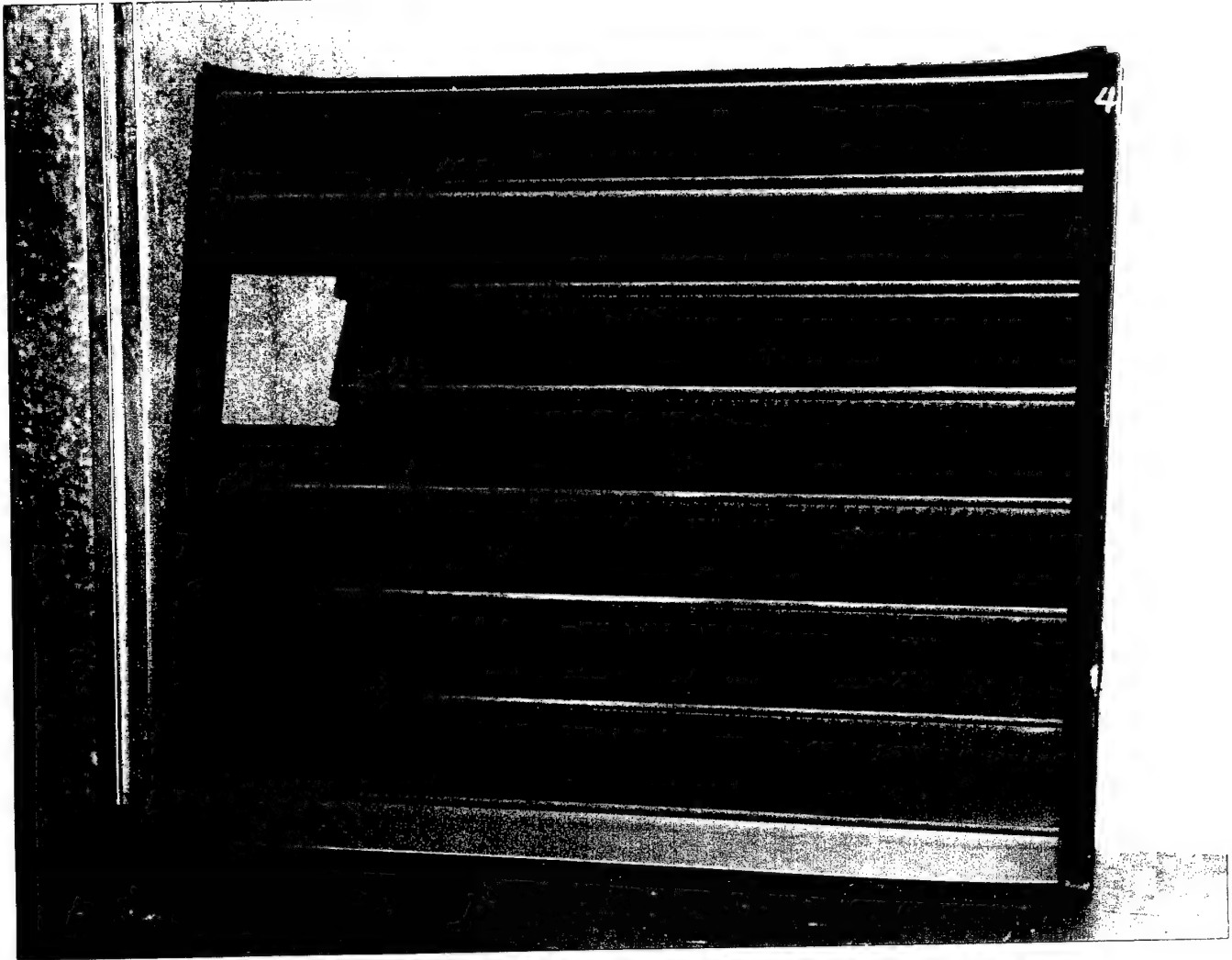


Fig. 8-A Test Specimen Insert # 4 at the End of First Thermal Cycle

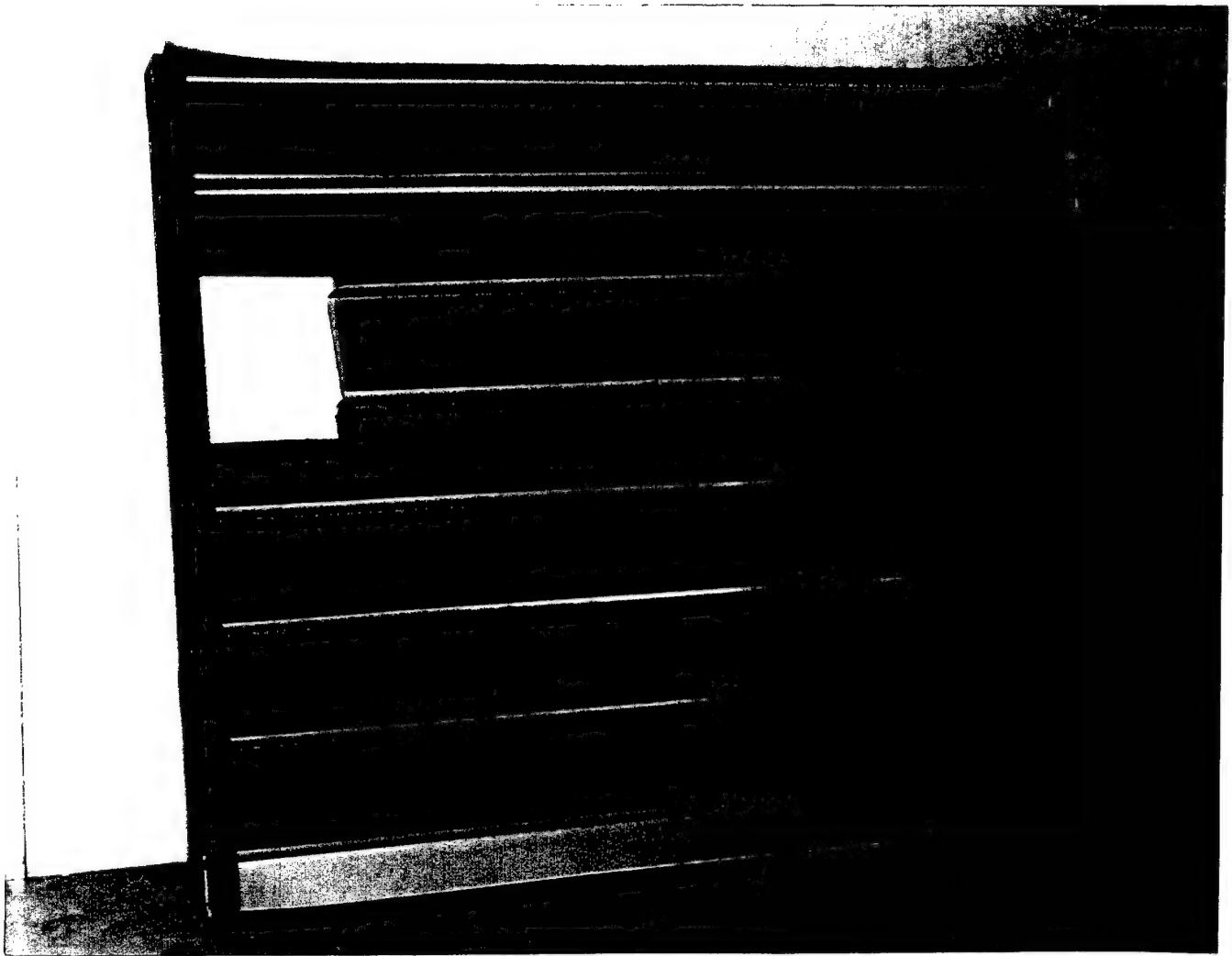


Fig. 8-B Test Specimen Insert # 4 at the End of Second Thermal Cycle

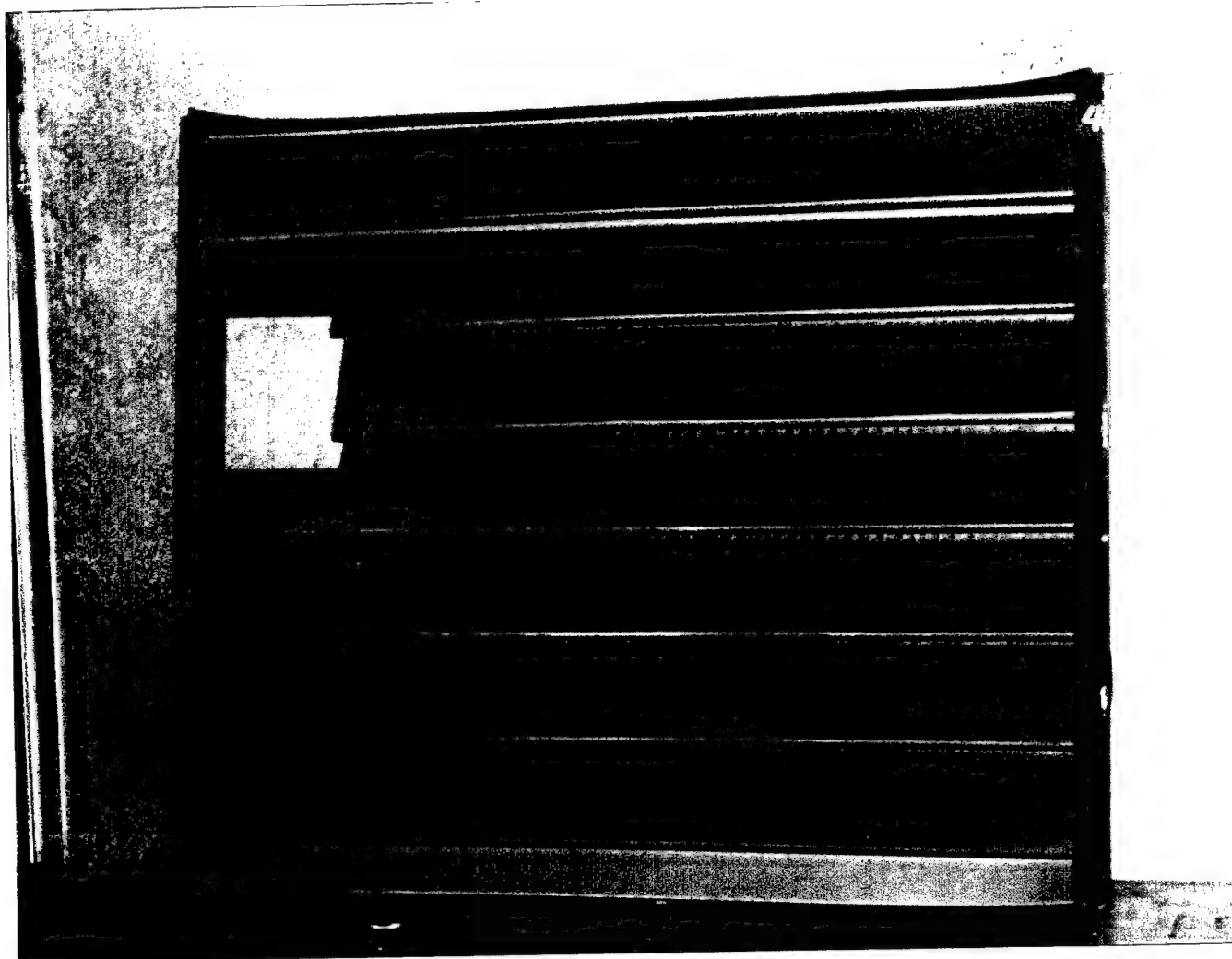


Fig. 8-C Test Specimen Insert # 4 at the End of Third Thermal Cycle

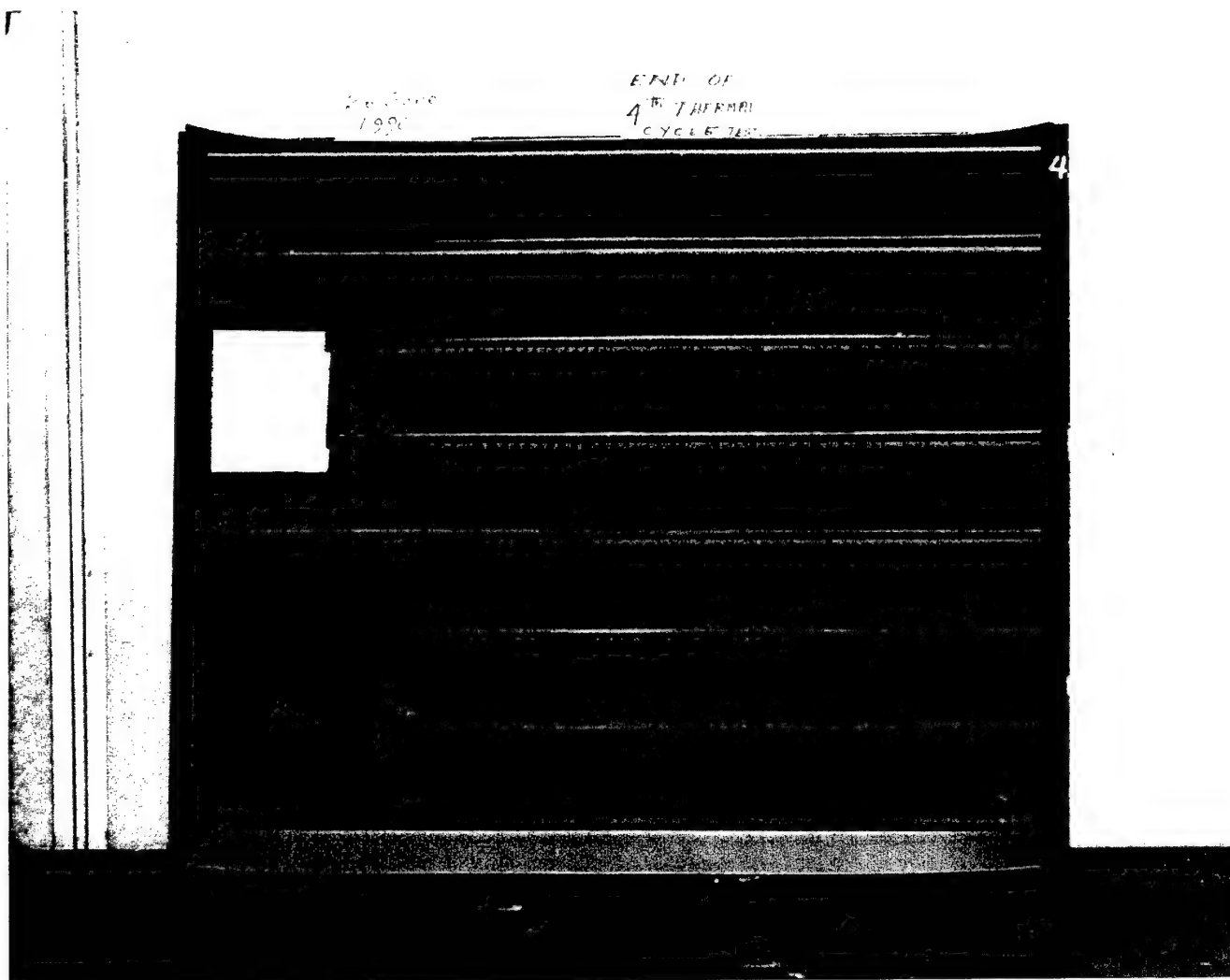


Fig. 8-D Test Specimen Insert # 4 at the End of Fourth Thermal Cycle

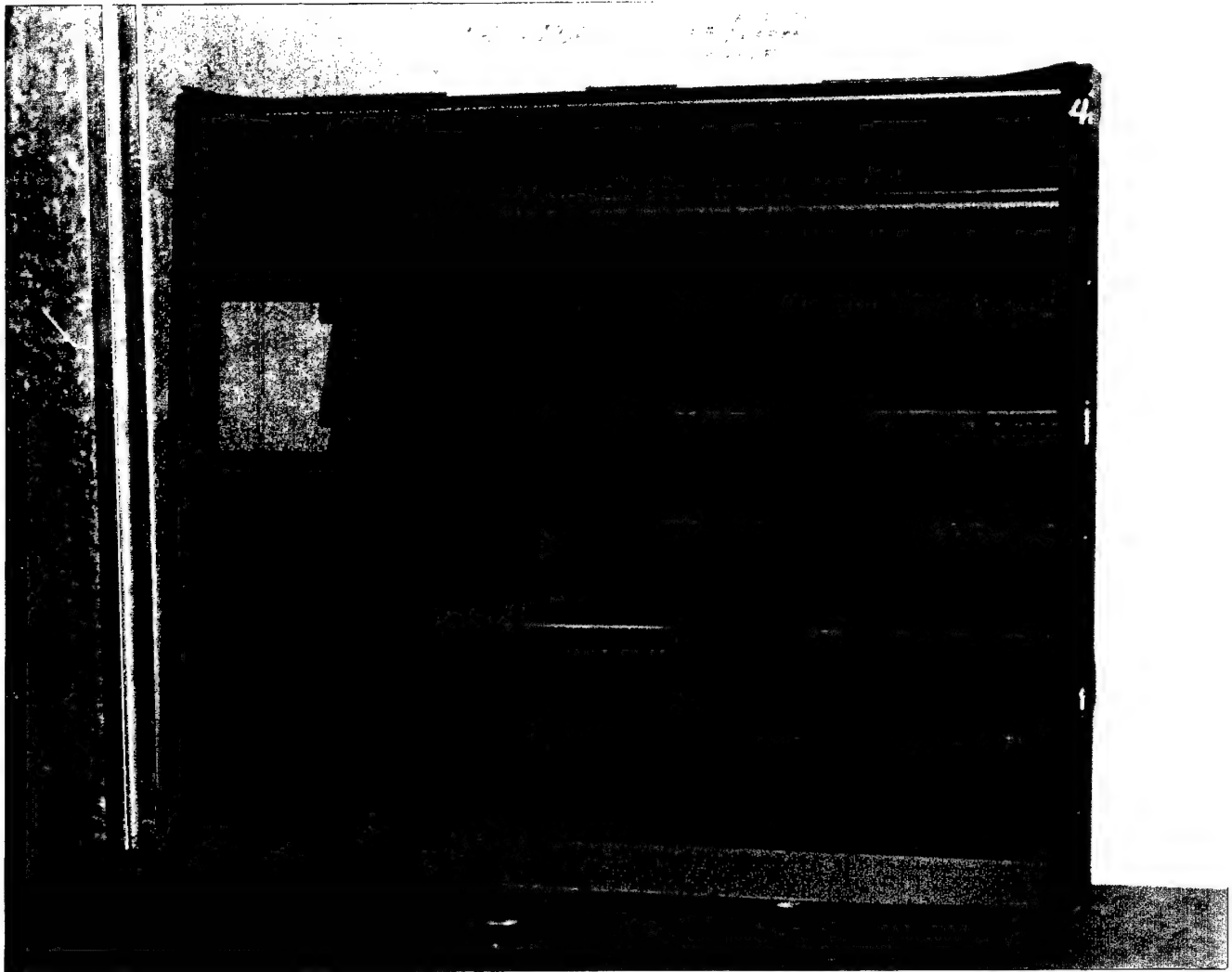


Fig. 8-E Test Specimen Insert # 4 at the End of Fifth Thermal Cycle

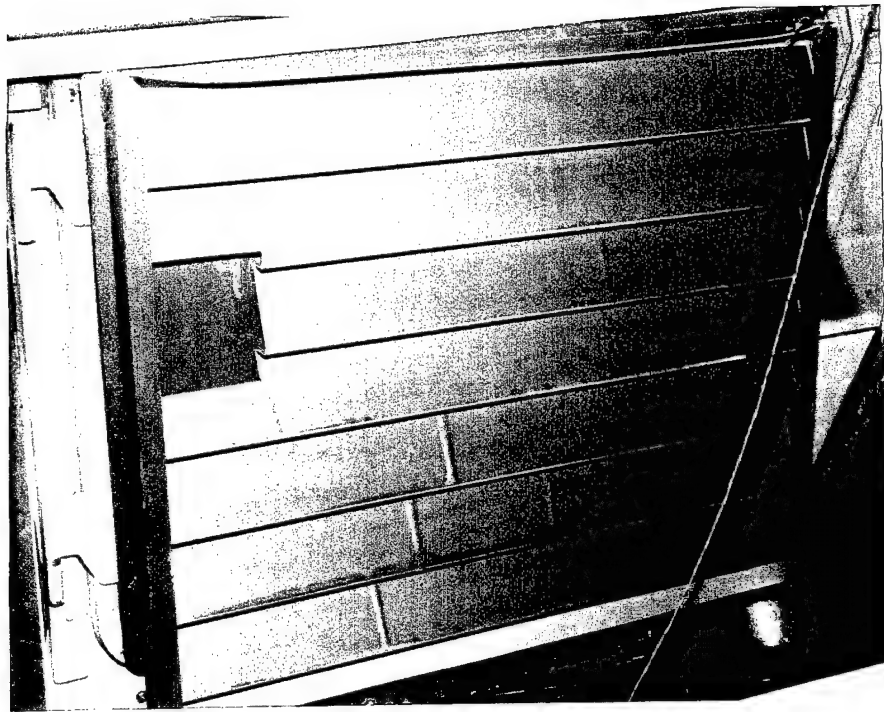


Fig. 8-F Test Specimen Insert # 4 at the End of 30 Hours of Solar Heating

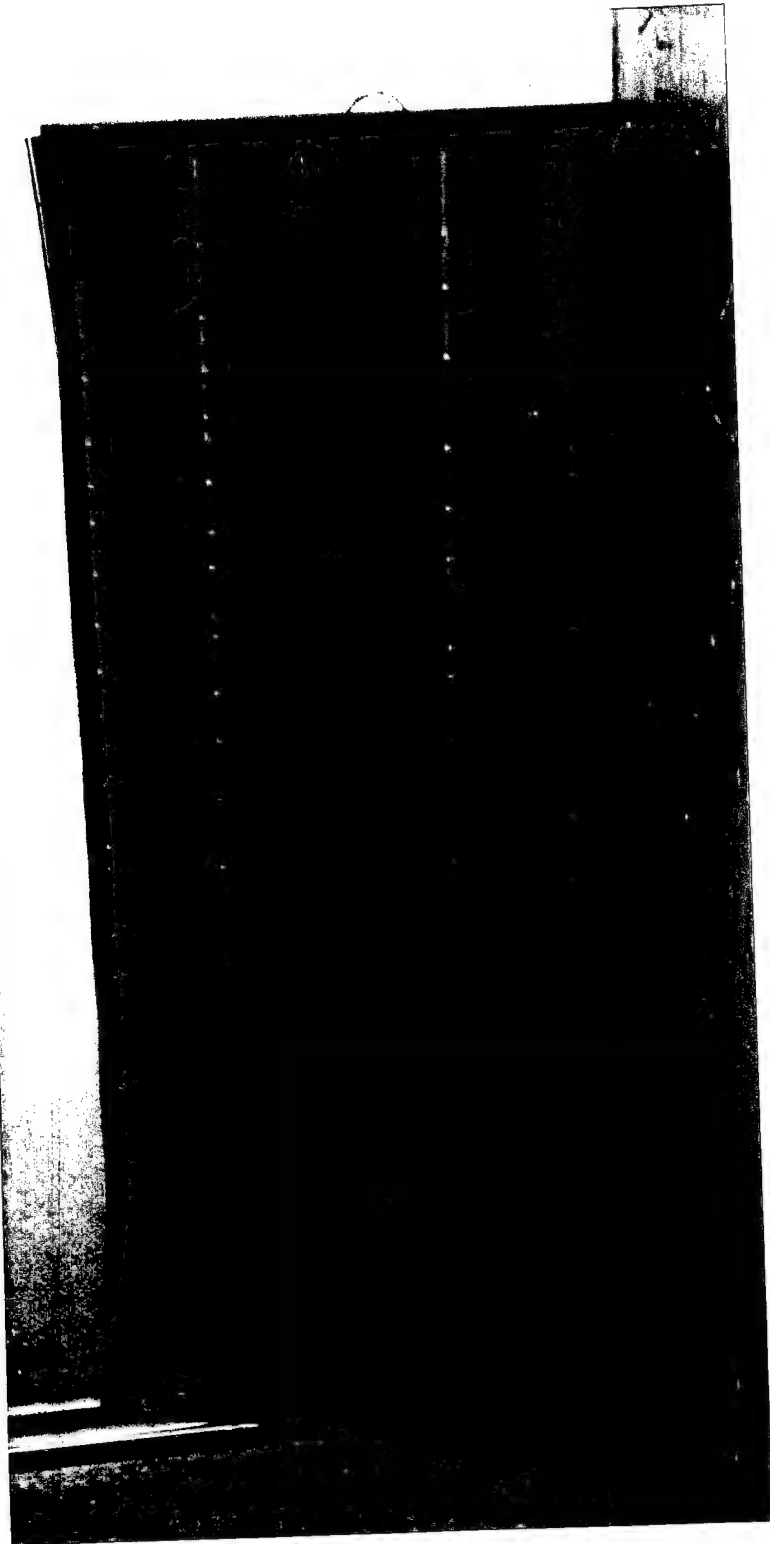


Fig.9-A Test Specimen Insert # 5 at the End of First Thermal Cycle

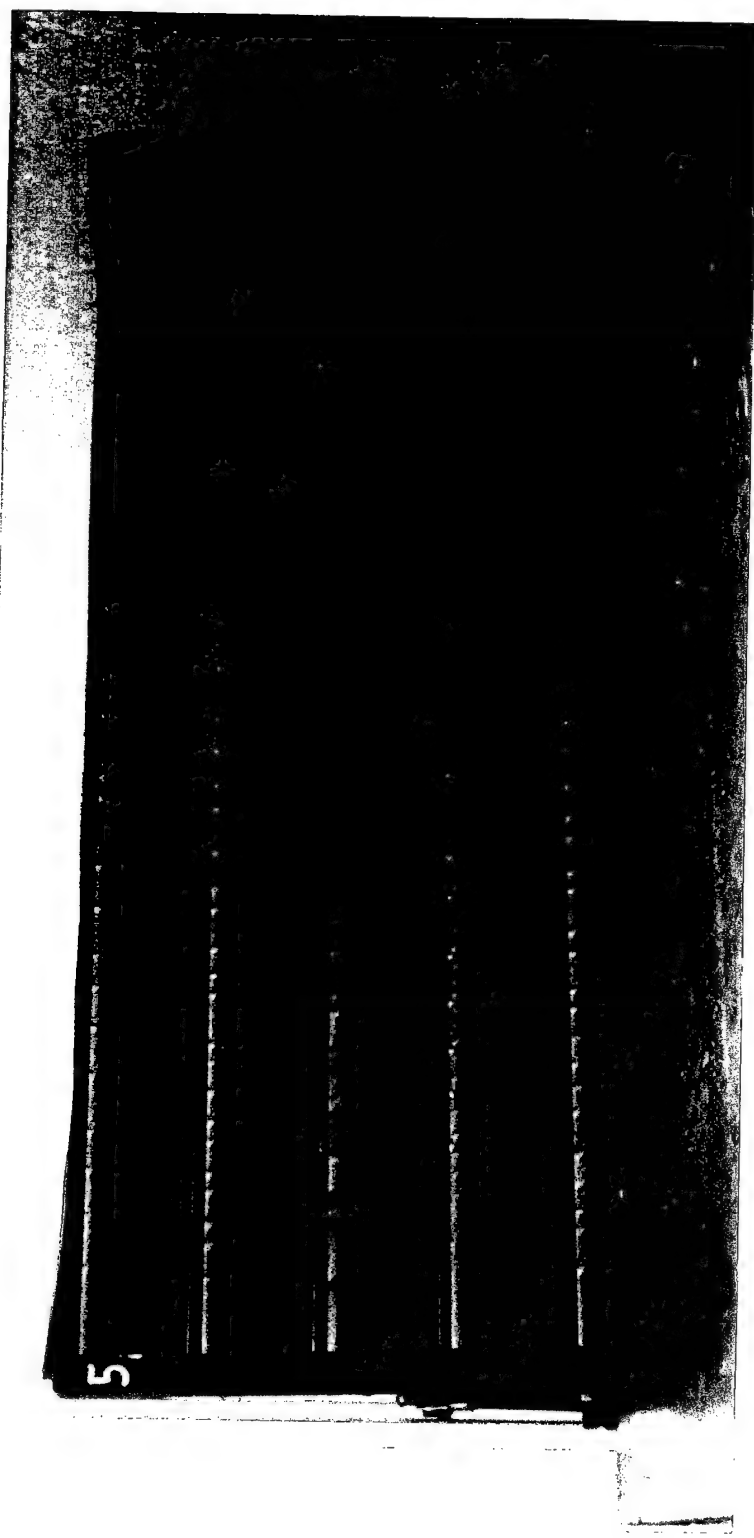


Fig.9-B Test Specimen Insert # 5 at the End of Second Thermal Cycle

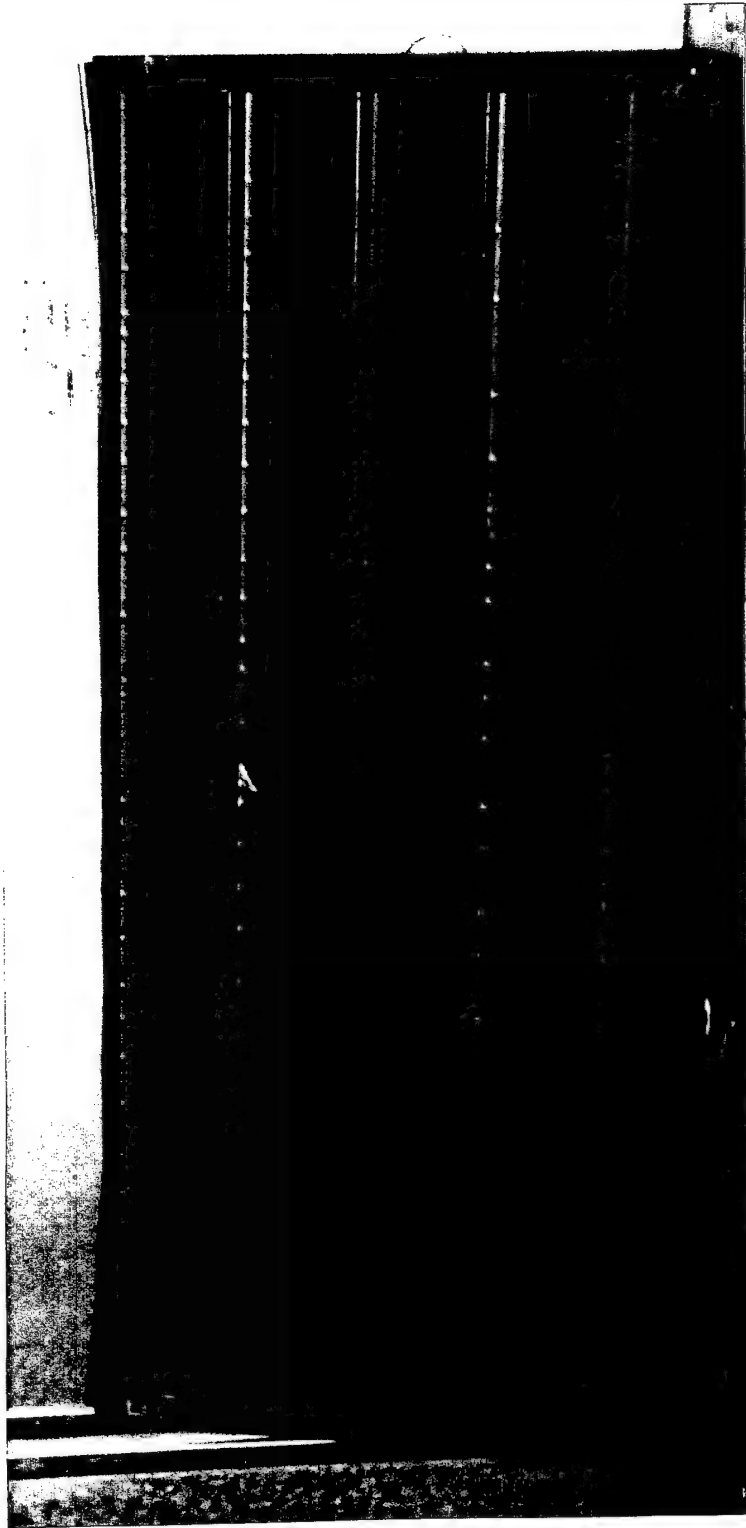


Fig.9-C Test Specimen Insert # 5 at the End of Third Thermal Cycle

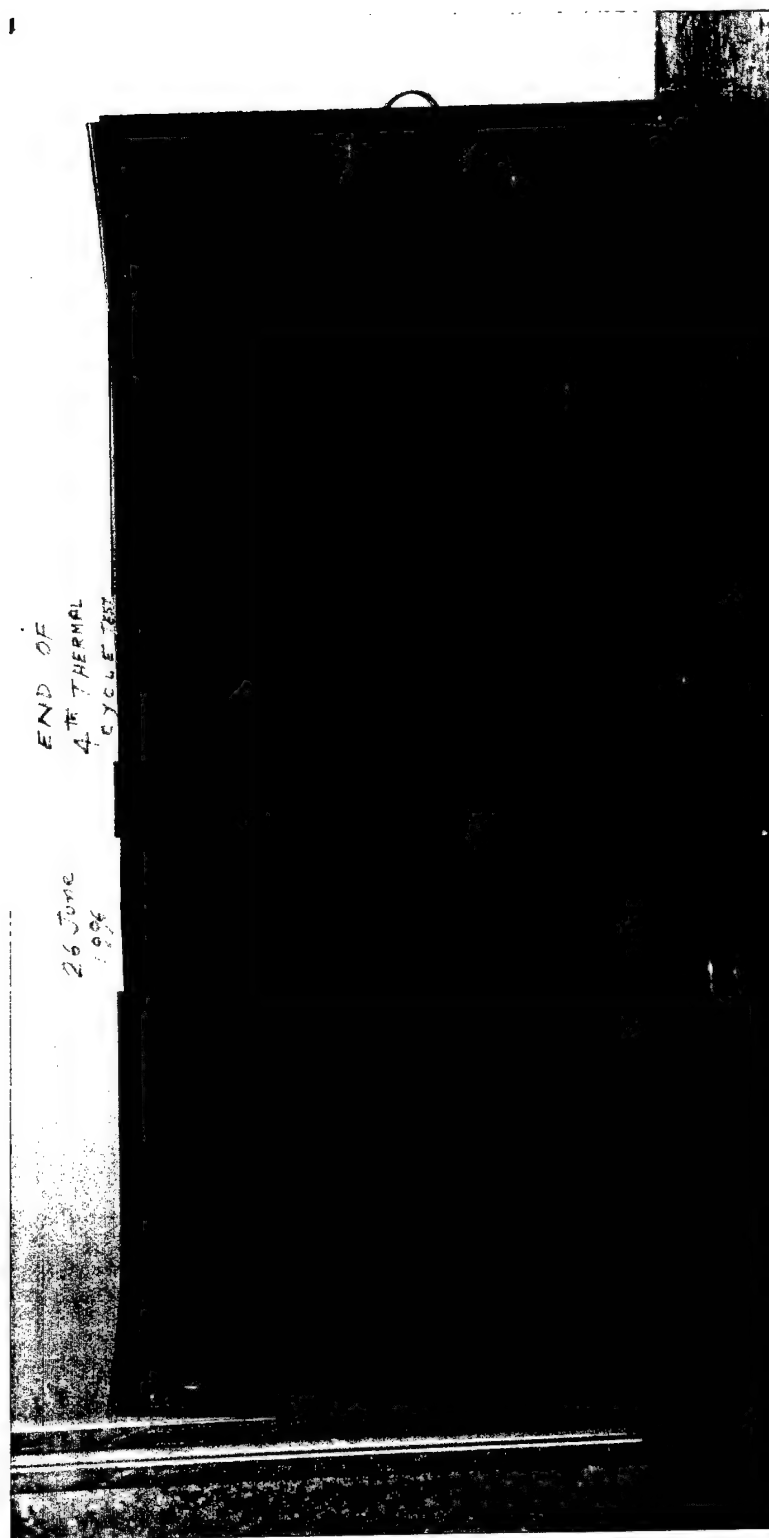


Fig.9-D Test Specimen Insert # 5 at the End of Fourth Thermal Cycle

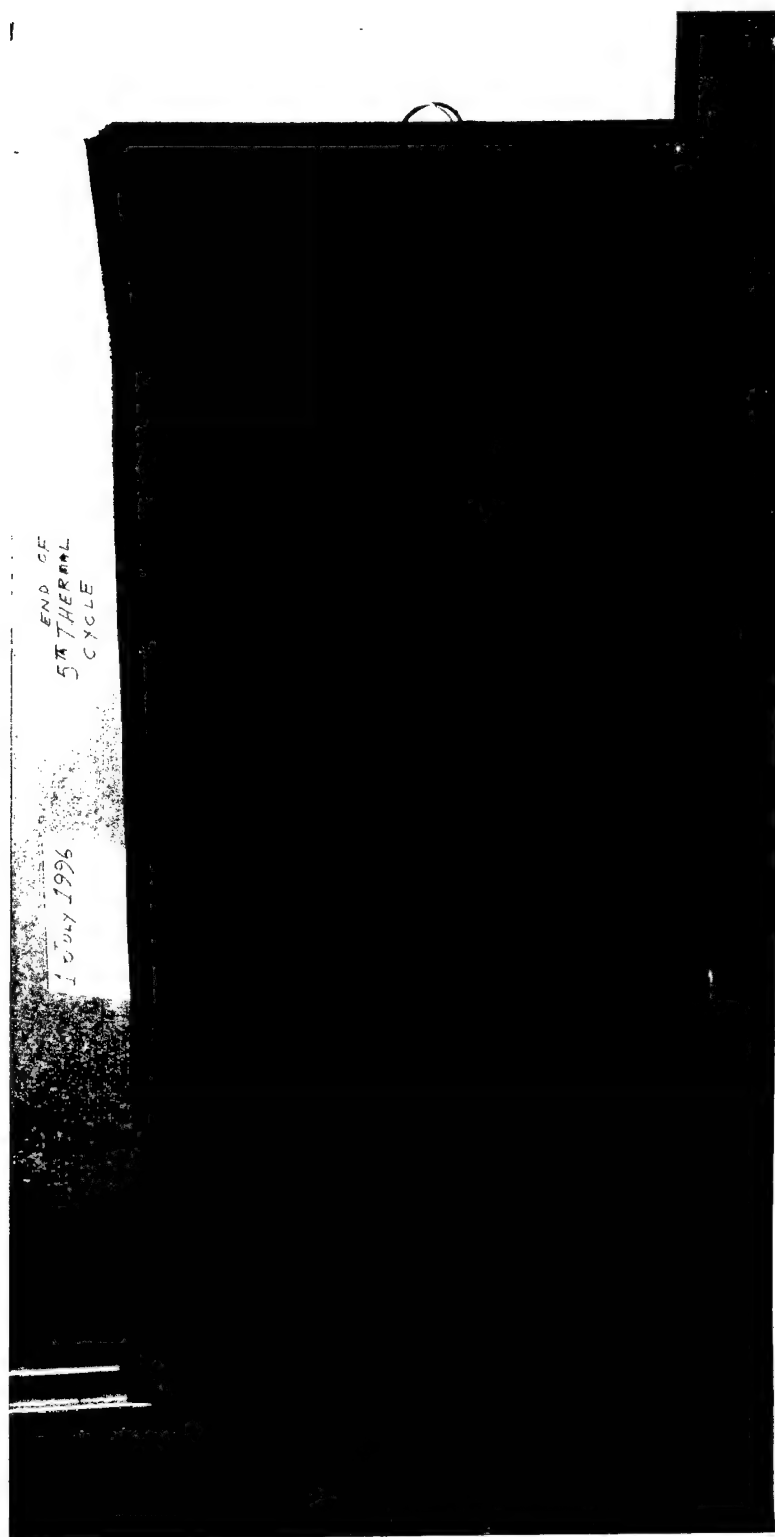


Fig.9-E Test Specimen Insert # 5 at the End of Fifth Thermal Cycle

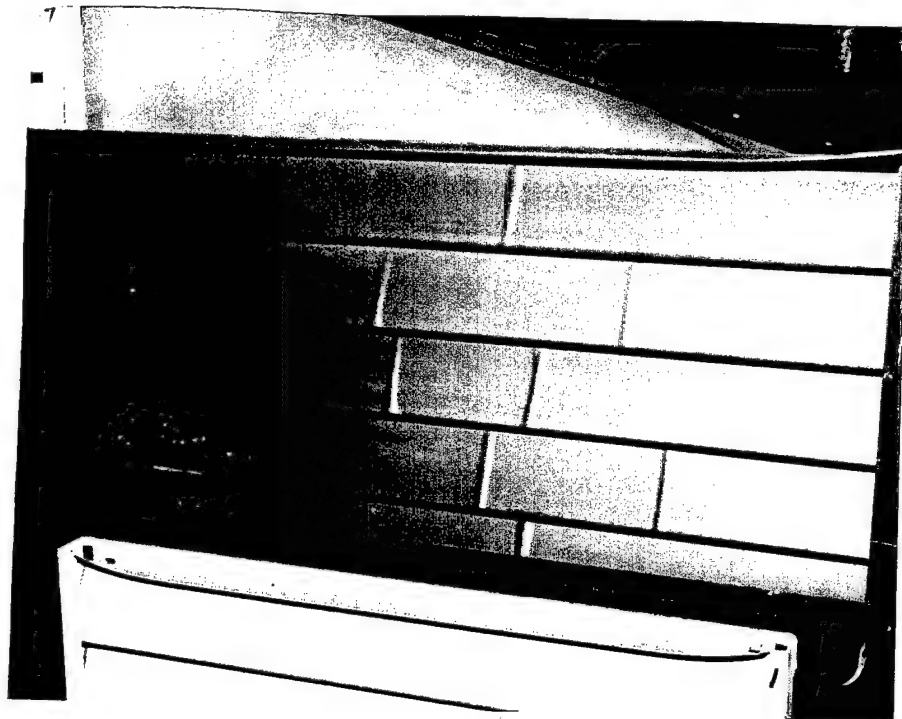


Fig. 9-F Test Specimen Insert # 5 at the End of 30 Hours of Solar Heating



Fig. 10-A Test Specimen Insert # 6 at the End of First Thermal Cycle

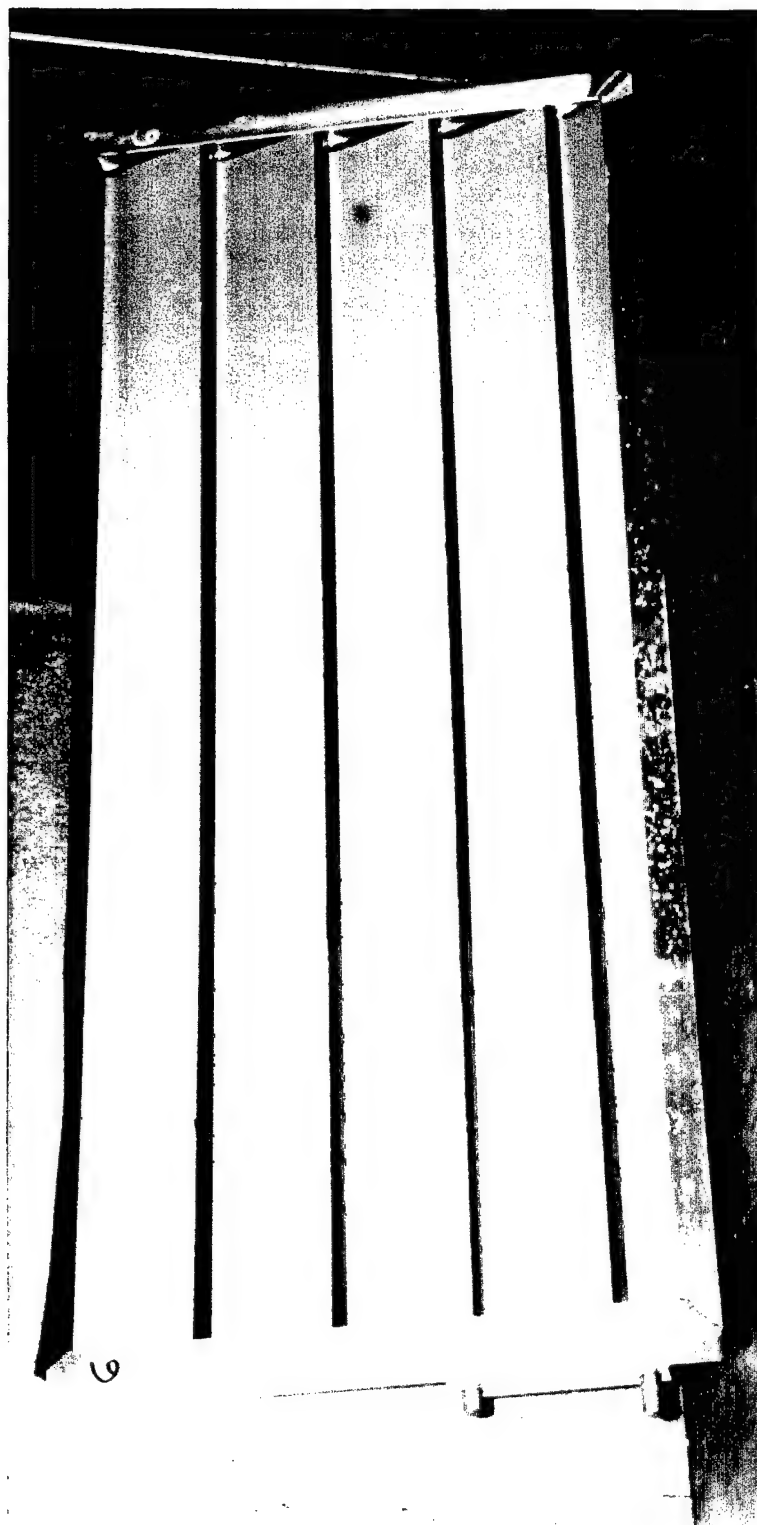


Fig. 10-B Test Specimen Insert # 6 at the End of Second Thermal Cycle

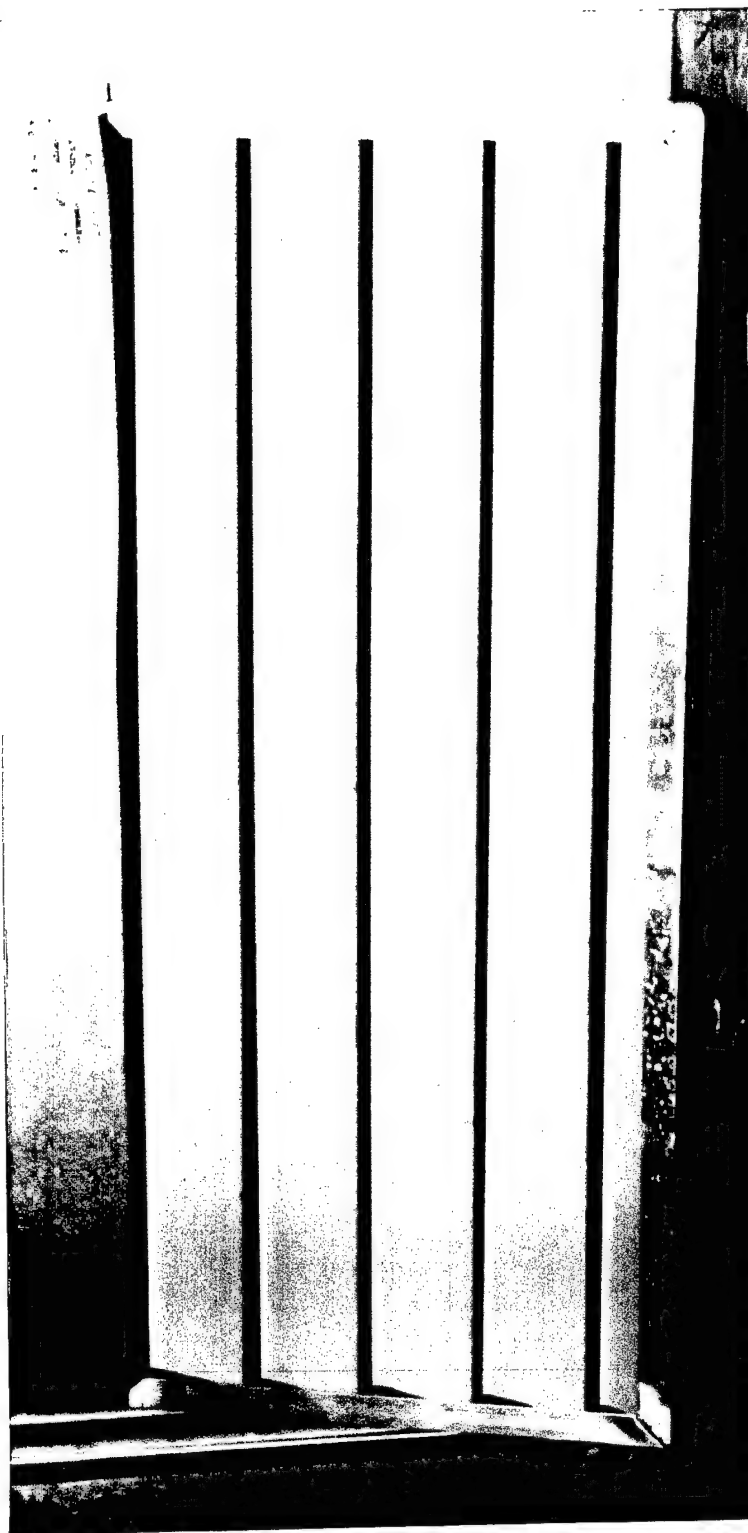


Fig. 10-C Test Specimen Insert # 6 at the End of Third Thermal Cycle

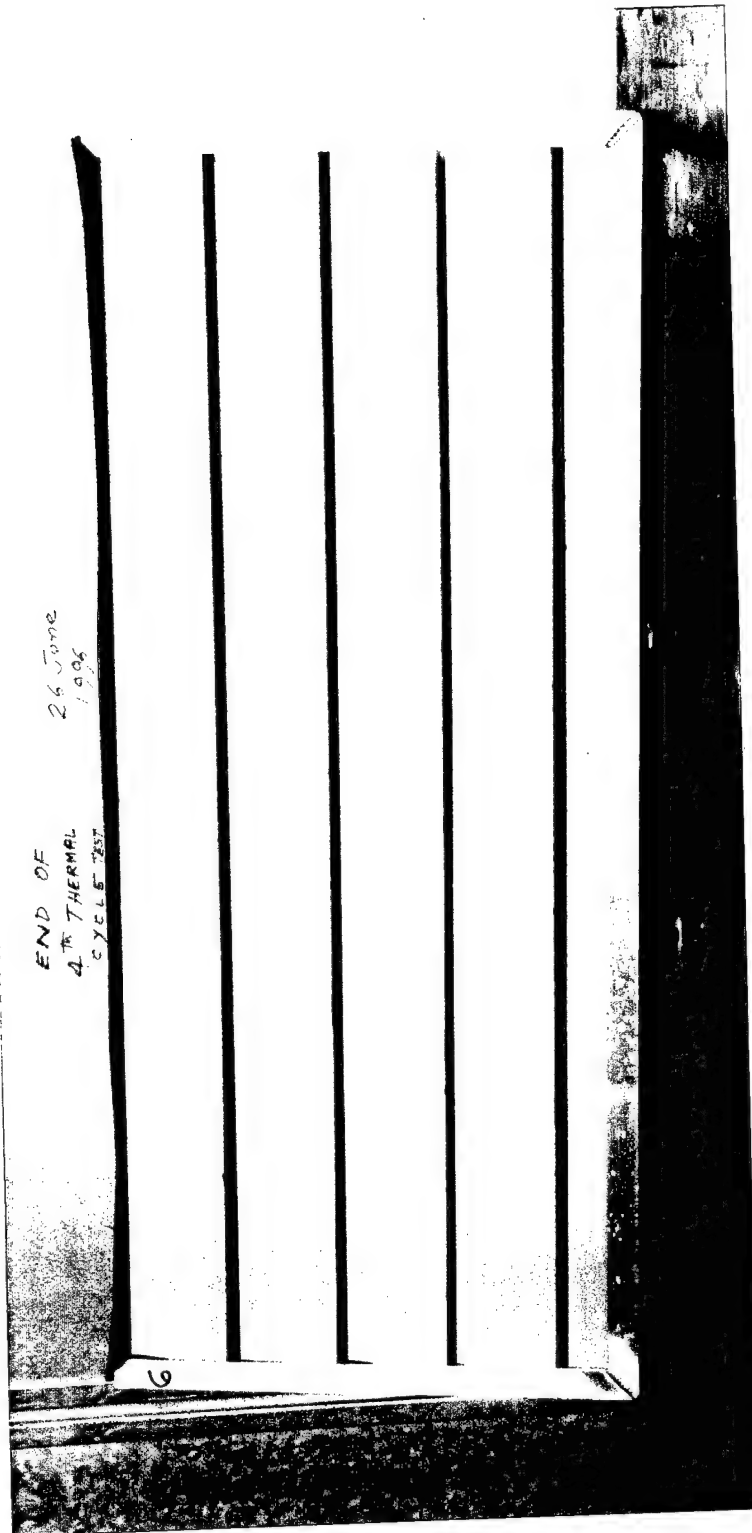


Fig. 10-D Test Specimen Insert # 6 at the End of Fourth Thermal Cycle

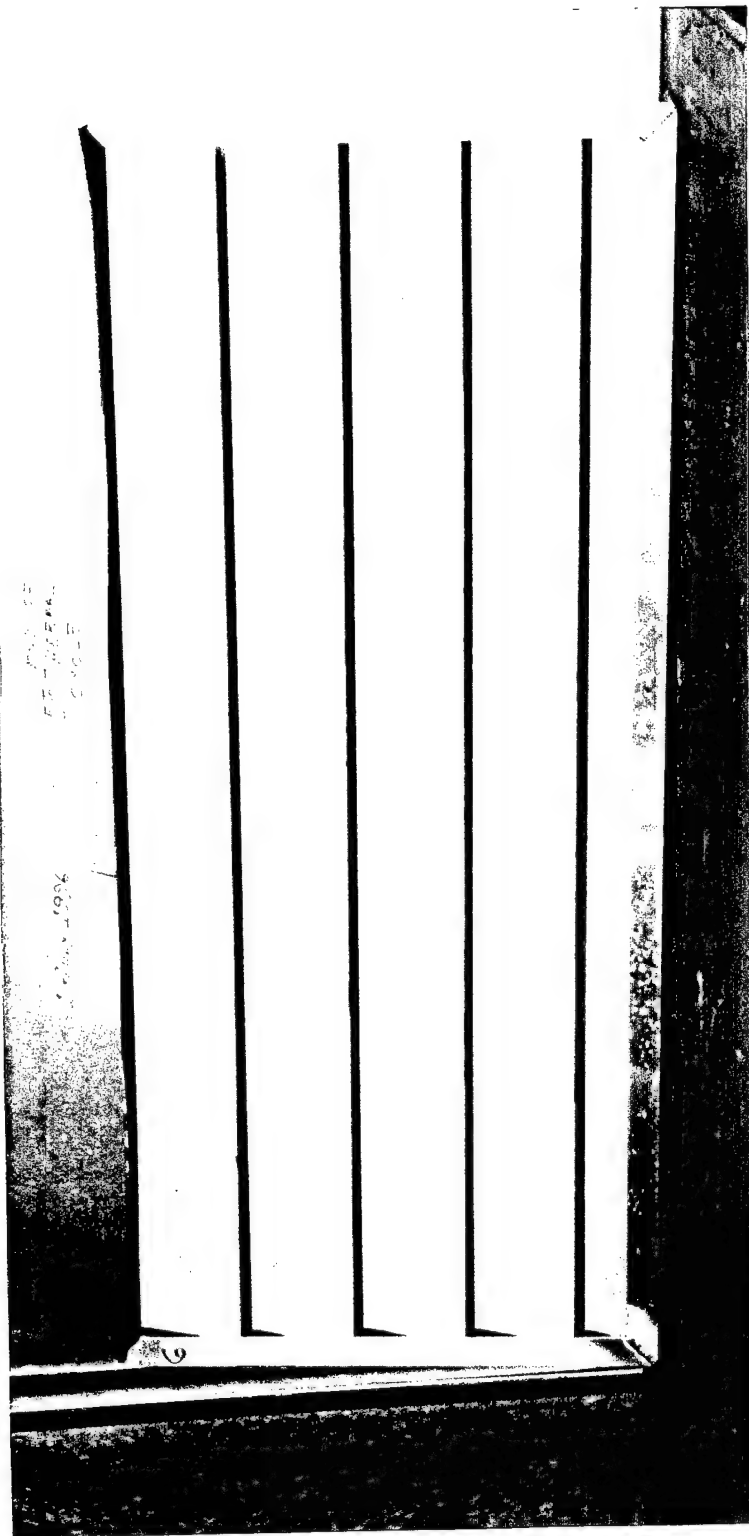


Fig. 10-E Test Specimen Insert # 6 at the End of Fifth Thermal Cycle



Fig. 10-F Test Specimen Insert # 6 at the End of 30 Hours of Solar Heating

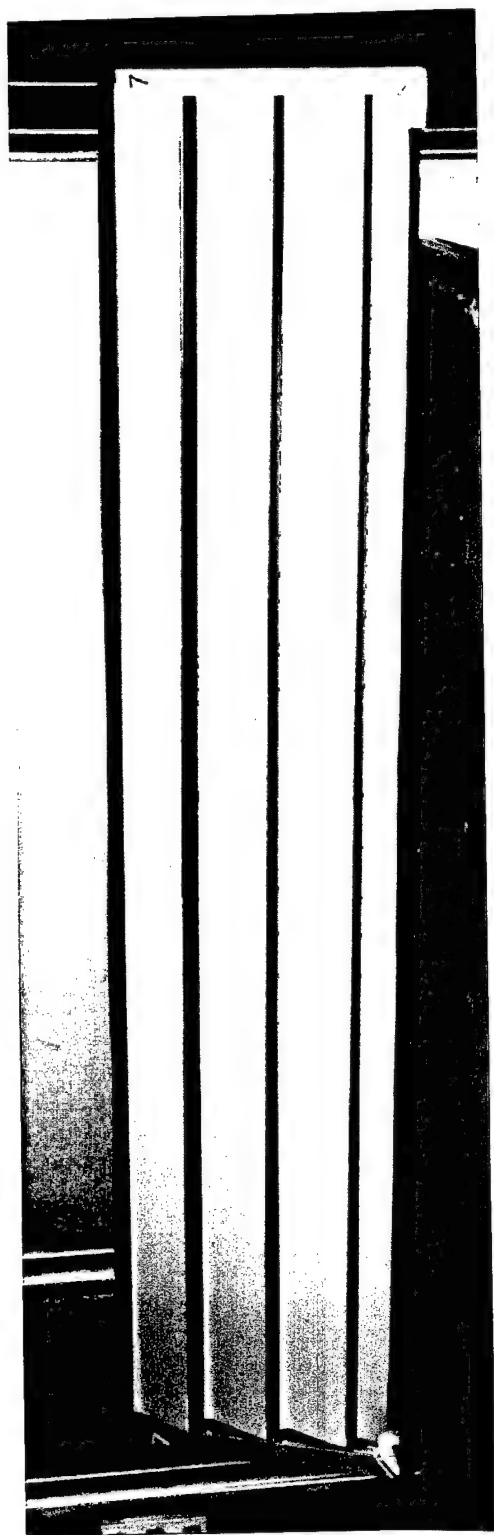


Fig. 11-A Test Specimen Insert # 7 at the end of First Thermal Cycle

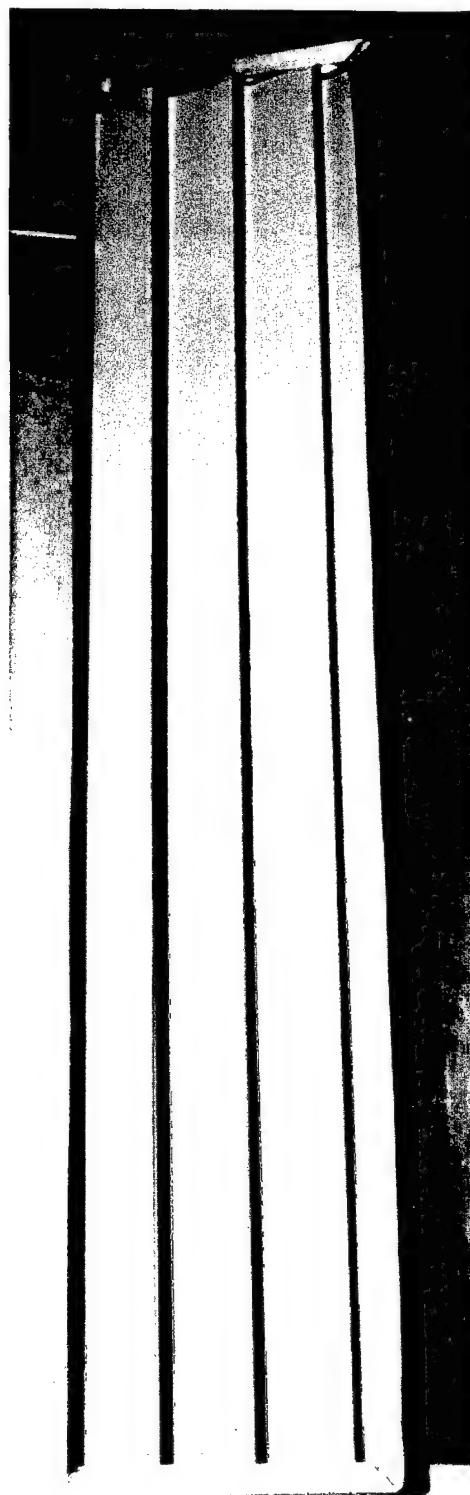


Fig. 11-B Test Specimen Insert # 7 at the End of Second Thermal Cycle

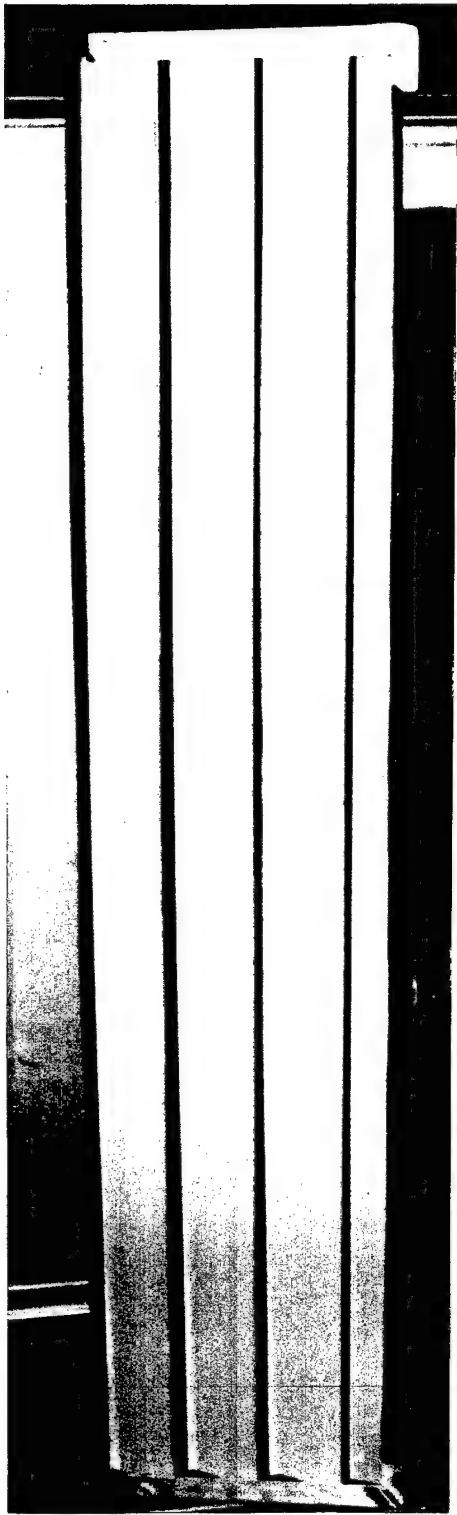


Fig.11-C Test Specimen Insert # 7 at the end of Third Thermal Cycle

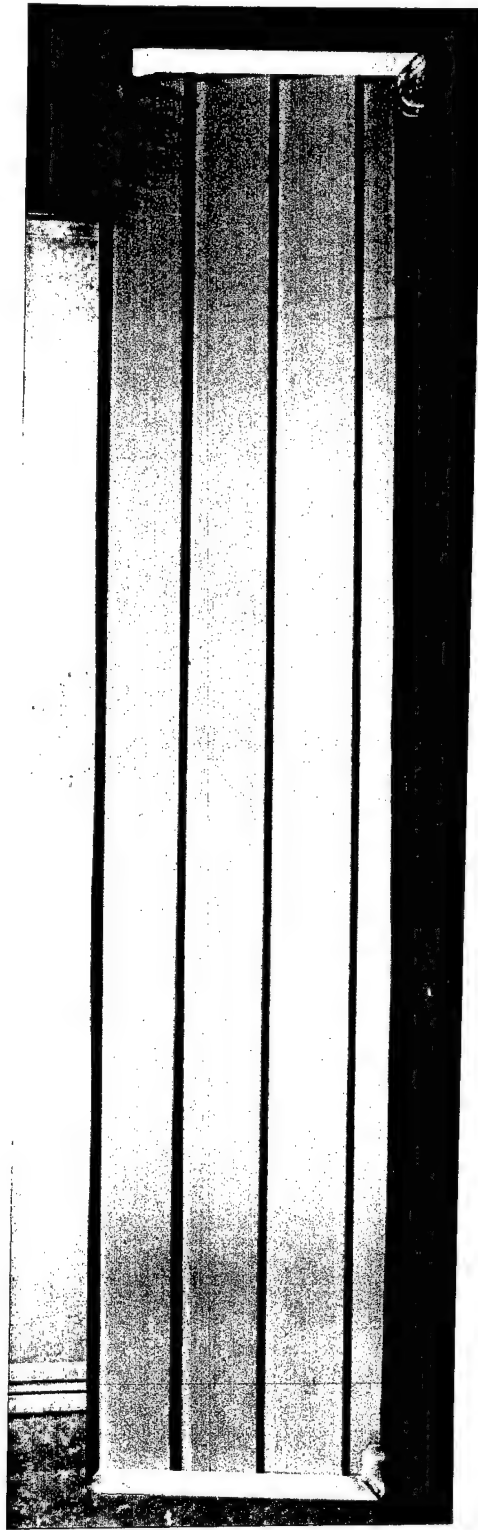


Fig.11-D Test Specimen Insert # 7 at the End of Fourth Thermal Cycle

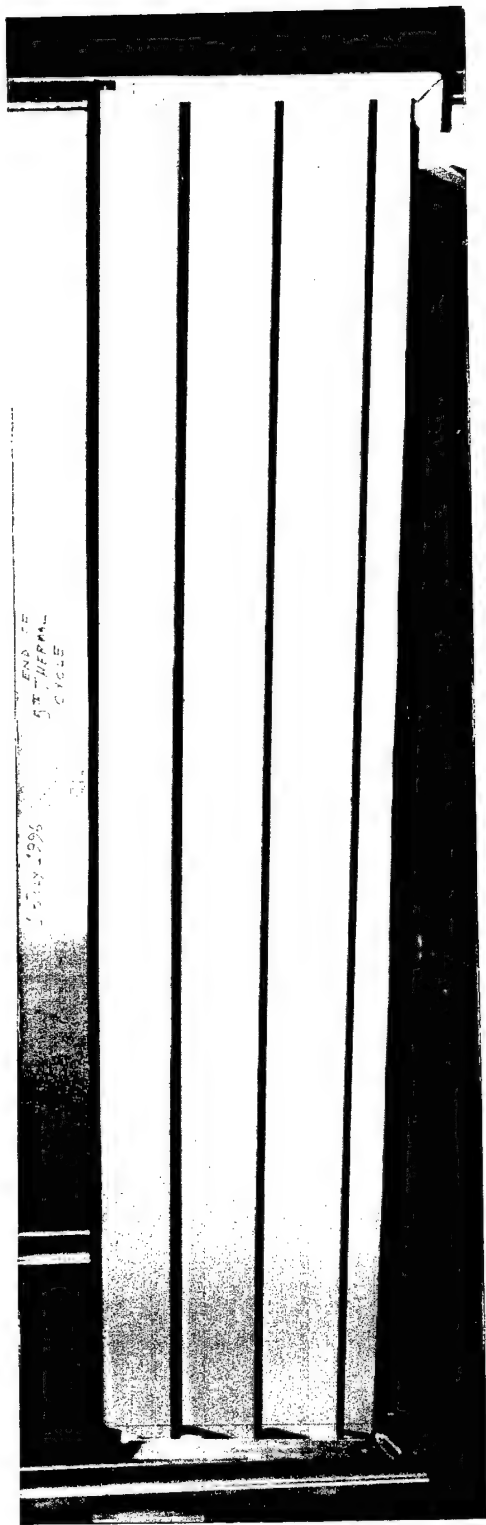


Fig. 11-E Test Specimen Insert # 7 at the End of Fifth Thermal Cycle

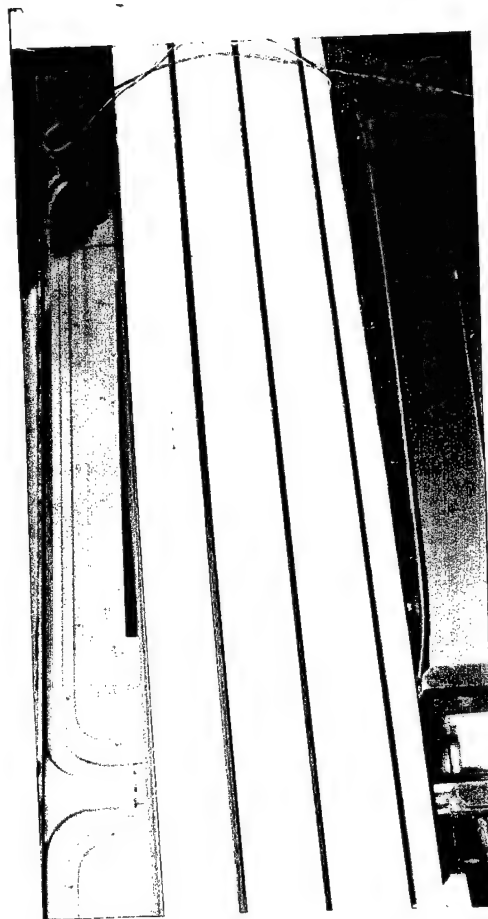


Fig. 11-F Test Specimen Insert # 7 at the End of 30 Hours of Solar Heating

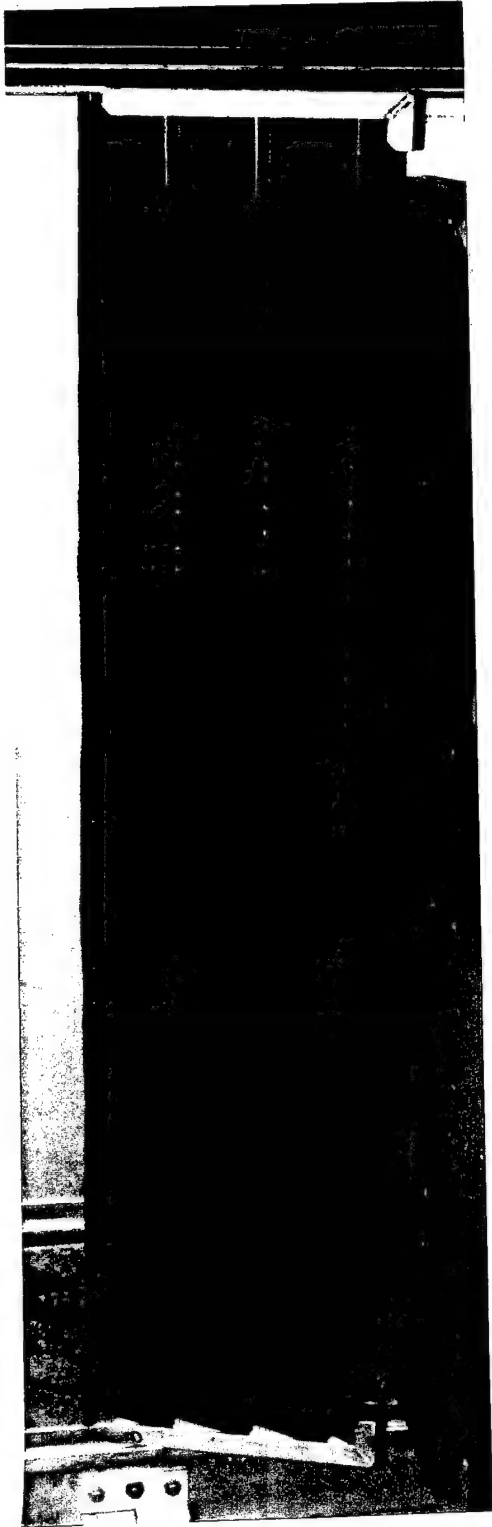


Fig.12-A Test Specimen Insert # 8 at the end of First Thermal Cycle



Fig.12-B Test Specimen Insert # 8 at the End Second Thermal Cycle

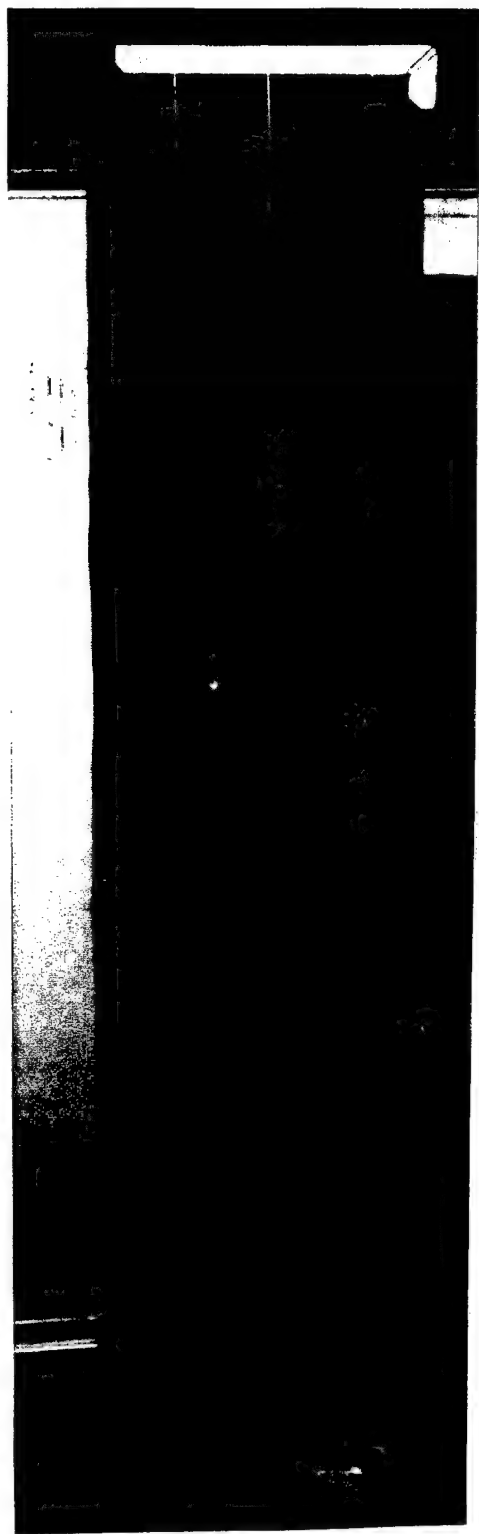


Fig. 12-C Test Specimen Insert # 8 at the end of Third Thermal Cycle

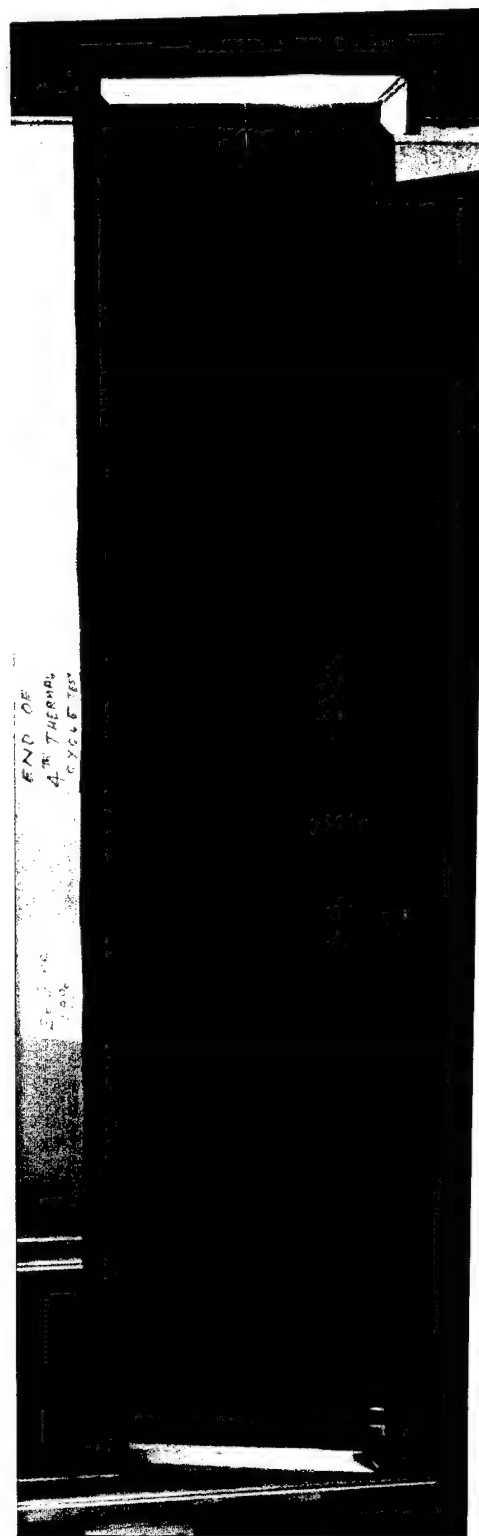


Fig. 12-D Test Specimen Insert # 8 at the End Fourth Thermal Cycle

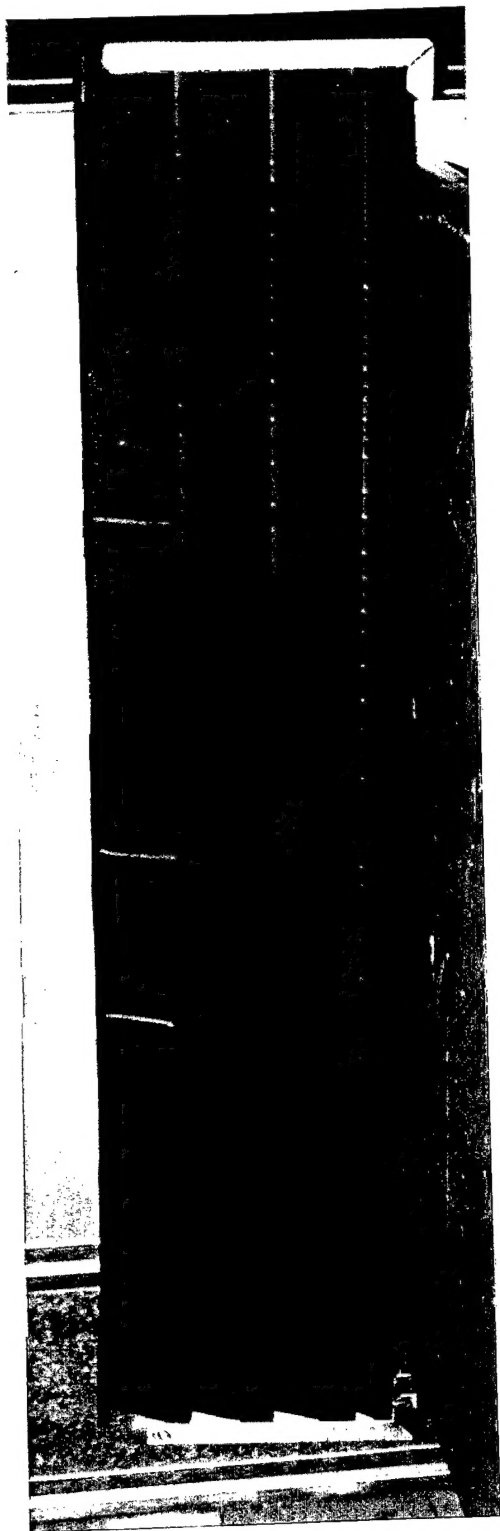


Fig. 12-E Test Specimen Insert # 8 at the End of Fifth Thermal Cycle



Fig. 12-F Test Specimen Insert # 8 at the End of 30 Hour Solar Heating

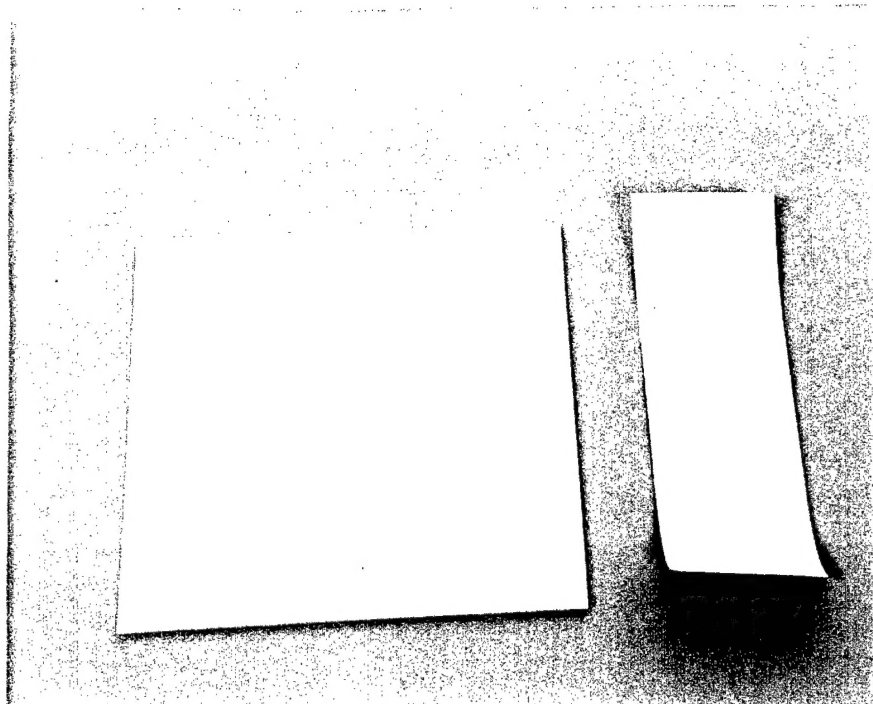


Fig. 13 Boltaron 1050-3719 Thermoplastic Pigmented with Tan Color
and Tan Color I.D. Tape

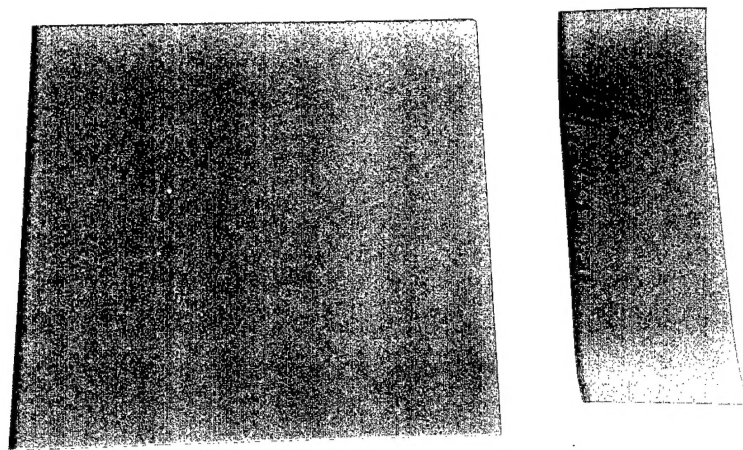


Fig. 14 Boltaron 1050-7344 Thermoplastic Pigmented with Green Color
and Green Color I.D. Tape

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